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Evaluation of Horse Clam Stock Dynamics for a Directed Subtidal Horse Clam (*Tresus capax* and *Tresus nuttallii*) Fishery in British Columbia

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1. Abstract

Biological information essential for addressing ecological concerns, assessing population stock dynamics, and evaluating fishing strategies for a directed fishery proposed for horse clams were examined. The depth distribution of horse clams appeared to extensively overlap with geoducks in the subtidal zones. The possible detrimental effect caused by horse clam exploitation on geoduck populations is, at present, unknown and should be examined in the future. The current depth restriction for horse clam and geoduck fishing, which is shallower than 10 feet (3.06 m) below chart datum, appears to be inadequate to sufficiently protect the eelgrass habitat in some areas. A general survey protocol was outlined for obtaining biological and ecological information, such as horse clam biomass, natural mortality rate, growth, and eelgrass distribution. A computer stochastic model was developed to evaluate the effect of alternative fishing schemes and exploitation rates on the reproduction potential of horse clam populations, based on known natural mortality and growth rates and age at vulnerability to fishing. Highly precautionary biological reference points were recommended for the initial phase of the directed fishery.

1.1 Résumé

Cette étude a examiné l'information biologique essentielle pour aborder les préoccupations écologiques que soulève une pêche dirigée proposée de la fausse-mactre ainsi que pour évaluer la dynamique des stocks de ce mollusque et les stratégies de pêche possibles. En zone subtidale, la répartition de la fausse-mactre selon la profondeur semble chevaucher considérablement celle de la panope du Pacifique. Actuellement inconnu, l'effet néfaste que pourrait avoir l'exploitation de la fausse-mactre sur les populations de panopes du Pacifique devrait être étudié. La limite actuelle de profondeur maximale de récolte de la fausse-mactre et de la panope, soit 10 pieds (3,06 m) sous le zéro des cartes, ne semble pas protéger suffisamment l'habitat de la zostère marine dans certaines régions. Un protocole général de relevé a été établi pour obtenir des données biologiques et écologiques, comme la biomasse, la croissance et le taux de mortalité naturelle de la fausse-mactre ainsi que la répartition de la zostère marine. Fondé sur les connaissances concernant la mortalité naturelle, les taux de croissances et l'âge de vulnérabilité à la pêche de la fausse-mactre, un modèle informatique stochastique a été mis au point pour évaluer l'effet de divers modes de récolte et taux d'exploitation sur la capacité de reproduction des populations de ce mollusque. Des points de référence biologiques très prudents sont recommandés pour la première phase de la pêche dirigée.

2. Introduction

Two horse clam species, *Tresus capax* and *T. nuttallii*, have been incidentally harvested in the subtidal zones of British Columbia (B.C.) since 1979. Lauzier *et al.* (1998) reviewed the biology and fisheries of these two horse clam species. No commercial harvest of horse clams exists in the intertidal zone of B.C. Due to a lack of appropriate stock assessments, managers have restricted exploitation of horse clams as only incidental by-catch to the geoduck (*Panopea abrupta*) in B.C. This incidental fishery, since 1992, has been a 3-year rotation fishery, co-incident with the geoduck fishery management plan (Heizer 1999). Horse clam catch ceilings, loosely based on historical catches, have been limited to 5 t in Pacific Fishery Management Area (PFMA) 15 and 24 with high historical landings, to 2 t in PFMA 14, 16, 18 and 25 with moderate historical landings, and to 1 t in PFMA 12, 13, 17, 19, 23, 26, and 27 with low historical landings (Harbo and Hobbs 1997, Heizer 1999). Fishing for horse clams has been restricted to 10 feet (3.06 m) below chart datum in an attempt to protect eelgrass beds, which support herring spawning and may provide a habitat for horse clams. There are concerns, however, about the impact of harvesting horse clams in eelgrass beds which may extend deeper than 10 feet below chart datum.

Commercial harvesters of horse clams now wish to expand the fishery from an incidental to a directed fishery for the subtidal horse clam. A sound management plan for a directed horse clam fishery requires an evaluation of the stock dynamics, alternative management options and ecological impacts. Biological information on natural mortality, growth, longevity, vulnerability of age to fishing, relative density and extent of eelgrass distribution have been gathered from some areas.

The objectives of this paper are to review the existing fisheries-related biological data on horse clams, inspect the extent of overlap between distributions of horse clams and geoducks, examine the extent of eelgrass distribution, develop a general survey protocol, and model horse clam stock dynamics to obtain a range of exploitation rates (E) for both species of horse clams, as required by the fishery managers (Appendix 1).

3. Existing Biological Information

The biology of horse clam has been reviewed by Lauzier *et al.* (1998). Here we only examined biological information essential for addressing the ecological concerns, assessing stock dynamics, and evaluating fishing strategies.

3.1. Distribution and Relative Abundance

Two species of horse clams (*T. capax* and *T. nuttallii*) live in mud, sand and gravel substrates in B.C. waters. *Tresus nuttallii* is found from the low intertidal to subtidal depths of 50 m, buried to depth of $\geq$1 m, whereas *T. capax* is found from mid-intertidal to subtidal depths of 30 m, but may not be buried as deep in the subtidal (Bernard 1983; Haderlie and Abbott 1980). *Tresus nuttallii* may also live above the low intertidal, although this has not been documented (Lauzier *et al.* 1998). Subtidally, the relative composition of the two horse clam species varies considerably. In some areas, such as Ritchie Bay, Stubbs Islets, Klaskino Inlet and Newcastle Island, almost the entire horse clam population was composed of *T. nuttallii*, while in Seal Islets *T. capax* was overwhelmingly dominant (Table 1). In Comox Bar, just above half of the horse clam population was composed of *T. capax*, while in Epper Pass, Lemmens Inlet and Yellow Bank, more than half of the horse clams were *T. nuttallii* (Table 1).

Density of horse clam has been estimated in some areas. Horse clam densities estimated from study plots varied from 0.32/m^2 in Ritchie Bay (Campbell *et al.* 1990) to 4.54/m^2 at Seal Islets (Campbell and Bourne 2000). Goodwin and Shaul (1978) reported mean horse clam densities of 1.48/m^2 in Puget Sound, but much higher densities at Dungeness Spit. Diving observations in 1988 revealed that the mean density of horse clams was 2.33 pieces /m^2 in the Morfee Island (Harbo and Hobbs 1989). Estimates of subtidal horse clam density derived from geoduck surveys were comparatively low along the coast (Lauzier *et al.* 1998). As show factor (percent of neck showing above the substrate at any particular time) was not considered in these estimates, the true density may have been higher. These estimated densities may reflect relative abundances of horse clams in different surveyed areas. The mean density estimate varied between 0.01 and 0.12/m^2 in Kettle Inlet and Anderson Island in the North Coast, Hotspring Island, Cumshewa Inlet, and Houston Stewart in the Queen Charlotte Islands, Oyster River and Duncan Island in the Strait of Georgia, Ahousat and Winter Harbour in the West Coast of Vancouver Island (Lauzier *et al.* 1998). Mean density derived from a geoduck survey conducted in 1995 in the Yellow Bank/Elbow Bank area was relatively high, ranging from 0.29/m^2 in the Epper Pass, 0.46/m^2 in the Yellow Bank, 0.58/m^2 in the Elbow Bank and 0.81/m^2 in the Morfee/Dunlap (C. Hand unpublished data). The overall mean density was 0.55/m^2, more than 5 times as high as in the other geoduck areas surveyed, suggesting that the Yellow Bank/Elbow Bank area was a relatively high productive horse clam area. Highest historic landings of horse calms were produced in this area (Lauzier *et al.* 1998).

Data from geoduck surveys (C. Hand unpublished data) also indicated that depth distribution of horse clams and geoducks overlapped extensively (Fig. 1, Table 2), although variation in abundance with depth appeared to be different between species. The abundance of geoduck decreased with depth in most of the areas, whereas changes in abundance of horse clam by depth were variable. In Ahousat, Elbow Bank, Hotspring Island, North Epper Pass and Yellow Bank, horse clams were relatively abundant in the low depths between 0 and 6 m, whereas in Cumshewa and Kettle Inlet, they were more abundant in the depths between 3 and

12 m. Campbell and Bourne (2000) also found that density of horse clams was higher in the depth of 3-6 m than other sampled depths in Ritchie Bay. In Anderson Island, horse clam density was lower in depths <15 m than for depths between 15 and 18 m. Coincidentally, the highest density of geoduck, was also found in this depth range in the Anderson Island (Table 2).

3.2. Fishing Selectivity on Size and Age

Divers are generally not able to differentiate between the two species of horse clams or assess individual size, until animals have been extracted from the substrate. Also, divers usually have difficulty in seeing and/or collecting small horse clams. Analysis of length or age frequency distributions should indicate the vulnerability of size or age of horse clams to fishing.

Commercial and biological samples were collected from some areas, and their length or age frequency distributions were constructed. Mean shell length (SL) of *T. nuttallii* varied from 144 to 176 mm with an overall mean of 165.6 mm, whereas for *T. capax* mean SL varied from 113 to 159.8 mm with an overall mean of 135.9 mm (Table 3). The minimum SL for *T. nuttallii* varied between 73 and 140 mm with a mean of 109.1 mm, whereas for *T. capax* minimum SL varied between 54 and 154 mm with a mean of 113.7 mm (Table 3). When minimum SL was converted to age based on the von Bertalanffy equation established for *T. nuttallii* and *T. capax* in Lemmens Inlet (see Table 5a), equivalent minimum age range was 3.2 to 7.1 years for *T. nuttallii* and 2.1 to 10.1 years for *T. capax*. Ages of horse clam collected commercially from Comox Bar and Stubbs Island were estimated by counting annuli on the shells. The age range was found to be 6-15 and 8-19 years for *T. nuttallii* and *T. capax*, respectively, for the samples from Comox Bar, and to be 4-14 and 6-12 years for *T. nuttallii* and *T. capax*, respectively, for the samples from Stubbs Island (R. Harbo unpublished data).

How well these commercial biosamples represent small horse clams is unknown, as most young clams might have been disturbed but not harvested. Horse clams loose the ability to re-burrow at 60-75 mm SL (Pohlo 1964). This SL range is approximately equivalent to 2-3 years of age. Individuals larger than this size range or older than this age range may die soon after they have been disturbed or exposed but not harvested. Thus, the minimum size or age of horse clams starting to suffer from fishing mortality is probably smaller or younger than what most of the commercial samples suggested.

Age frequency distributions were constructed from the biological samples collected from the field studies in Ritchie Bay and Seal Islet by Campbell and Bourne (2000). *Tresus nuttallii* began to be vulnerable to fishing approximately at age 4 years and fully vulnerable at age 7 years in Ritchie Bay, and *T. capax* started to be vulnerable to fishing at age 3 years and fully vulnerable at age 4 years in Seal Islet. This vulnerability information appeared to be reasonable and was used in the model described below. The exploitable population of *T. nuttallii* and *T. capax* was almost equivalent to the entire spawning population, as *T. nuttallii* and *T. capax* was found to mature at age 3 and 3-4 years, respectively (Campbell *et al.* 1990).

3.3. Natural Mortality Rate and Growth

Instantaneous natural mortality rates (M) were estimated based on age frequency distributions (Ricker 1975) for *T. nuttallii* in Klaskino Inlet, Ritchie Bay, Comox Bar and Stubbs Island, and for *T. capax* in Seal Islets and Comox Bar (Campbell and Bourne 2000, R. Harbo unpublished data) (Table 4). Campbell and Bourne (2000) estimated total mortality rate (Z) by calculating the slope of the regression relationship between the natural log of the frequency and age of horse clams > 10 years, which would include mature (Campbell *et al.* 1990) horse clams fully recruited to the fishery and mainly on the descending right limb of the age frequency curve. We assumed that the total mortality rate reflected the natural mortality rate because most of the age frequencies of horse clams sampled were from areas that had little or no commercial fishing history. Campbell and Bourne (2000) used SYSTAT to calculate the slope of the regression line and associated 95 % confidence intervals. M varied from 0.2 to 0.6 with a mean of 0.4 for *T. nuttallii*. M also varied for *T. capax*, being 0.16 in Seal Islets and 0.48 (3 times as high) in the Comox Bar (Table 4). Approximate 95% confidence intervals were also estimated for *T. nuttallii* in Ritchie Bay and Klaskino Inlet, and for *T. capax* in Seal Islet (Campbell and Bourne 2000). Standard deviations were approximately calculated by dividing the confidence interval (the difference between the upper and lower confidence limit) by 2, resulting in an approximate mean coefficient of variation of 0.3. This uncertainty about the estimation of M was simulated in the rotation model described below.

Campbell *et al.* (1990) and Campbell and Bourne (2000) reported on von Bertalanffy equation (with associated 95% confidence intervals) (Table 5a). These uncertainties about the estimations were also incorporated into the rotation model. The corresponding standard deviation was calculated in the same way as described above.

Campbell *et al.* (1990) and Campbell and Bourne (2000) described the length (SL) and weight (W) relationship using the model:

$$\ln(W) = \ln A + B * \ln(SL)$$

where lnA and B are model parameters (Table 5b). To simulate the uncertainty about the mean weight for a given length or age, standard error of the mean weight for a given length was calculated and used in the rotation model.

Only total wet drained weight was used in this paper. Total wet drained weights were not obtained from the samples collected commercially from the Klaskino Inlet. Instead, they were estimated from the total wet weight (Campbell and Bourne, 2000). So the growth models (von Bertalanffy equation and length-weight model) established for *T. nuttallii* in Klaskino area were not considered for use in the rotation model. A preliminary examination on the impact of using alternative growth models established for horse clams in different areas was relatively small, when the percentage of the maximum spawning stock biomass per recruit was to be maintained above 50% for the stock. For the same E varying from 0.01 to 0.4 with an interval

of 0.01 and same M varying from 0.1 to 0.5 with an interval of 0.05, use of growth models for *T. nuttallii* in Ritchie Bay or Newcastle Island resulted in only $< \pm$ 2% difference in final results, when compared with the use of the growth models for *T. nuttallii* in Lemmens Inlet. Use of growth models for *T. capax* in Seal Islet results in < 3% difference in the final results, as compared with the use of the growth models for *T. capax* in Lemmens Inlet. We chose to use the von Bertalanffy model and length-weight conversion model established for *T. nuttallii* and *T. capax* in Lemmens Inlet in the rotation model.

3.4. Eelgrass Distribution

Eelgrass beds may provide a good habitat for horse clams (Stout 1967, Wendell *et al.* 1976) and support herring spawning (Haegele and Hamey 1979, Haegele and Miller 1979). Eelgrass beds should be well protected. Horse clam fishing is currently restricted to the depths >10 feet (3.06 m) below chart datum in an attempt to protect eelgrass beds. Examination of the adequacy of the current protection requires information on the depth distribution of eelgrass.

Unpublished data from geoduck surveys (courtesy C. Hand) provided an opportunity to preliminarily examine the eelgrass distribution. Presence of eelgrass in the surveyed quadrats was noted in the geoduck surveys. We use the percentage of quadrats with presence of eelgrass to represent the relative quantities of eelgrass in various depth ranges (Fig. 2. Table 6). In Ahousat, Cumshewa Inlet, Hotspring Island and Kettle Inlet, considerable amount of eelgrass appeared to exit below 3-4 m. Relatively smaller proportion of eelgrass appeared to extend beyond 3-4 m in Anderson Island and Yellow Bank/Elbow Bank area. In Cumshewa Inlet, presence of eelgrass was recorded from 9-15m (not shown in Fig. 2). Eelgrass found in this depth possibly drifted from shallow waters. No eelgrass was recorded in the Morfee/Dunlap area. This is only a very rough approximation of depth distribution for eelgrass. Eelgrass density distribution can not be properly evaluated without quantitative information, such as percentage of eelgrass coverage.

In the late 1970s a diving transect survey was carried out with a total of 118 quadrats to investigate vegetation distribution in the Meares Island section of Clayoquot Sound (Yellow Bank/Elbow Bank area), which is a productive area for horse clams. Eelgrass (sea grass) was found to be the predominant vegetation, as 104 of the 118 quadrats were dominated by eelgrass and only 14 quadrats were dominated by other types of vegetation (Haegele and Hamey 1979, Haegele and Miller 1979). Percentage of eelgrass coverage was recorded for quadrats with eelgrass as predominant vegetation (Table 7). The depth was known for 80 quadrats out of the 104 quadrats dominated by eelgrass. The survey was largely conducted shallower than 3.5m depths, as only 7 out of the 80 quadrats were located below 3.5 m. Apparently, a substantial amount of eelgrass was found deeper than 3.5 m below chart datum. On average, eelgrass covered 54% of the surveyed quadrats between 0.1 and 3.5 m and 31.4% of the surveyed quadrats between 3.6 and 6 m below chart datum respectively. The current depth of restriction appears to be inadequate enough to sufficiently protect the eelgrass

habitat in this area. However, the number of surveyed quadrats below 3.5m was small.

The quantitative relationship between the distribution and abundance of horse clams and eelgrass requires further investigation as part of ongoing surveys.

4. Surveys

Prior to estimating quotas for a directed commercial fishery on horse clams, stock biomass and an appropriate E should be determined for specific beds. To estimate a precautionary E, data on M, growth, species composition and age vulnerability to fishing are required for modelling (e.g., the rotation model describe in this paper). In addition, surveys are required to estimate the abundance and distribution of horse clams and eelgrass, so that horse clam biomass can be calculated and an appropriate depth harvesting restriction can be determined for each area.

4.1. Biomass and distribution estimates

The three main phases that need to be considered in surveying horse clam biomass in specific areas are as follows.

Phase 1, a preliminary/exploratory phase, should be to establish the general locations and extent of horse clam beds in a specified area (e.g., PFM area or sub area). This could be accomplished by using a combination of existing fishery dependent data (e.g., log book information, interviews with fishermen) and rapid broad brush (systematic) surveys using timed swims or some other methods (e.g., Questar Tangent) to establish substrates, existence and locations of most subtidal horse clam beds in an area.

Phase 2, abundance estimate phase, should establish the extent and biomass of horse clams in 3-5 randomly selected beds in each specific area using transect surveys. Transect and biosample surveys, similar to those used for geoduck (e.g., Campbell *et al.* 1998; Campbell and Rajwani 1998; Hand and Dovey 1999), should be conducted to determine the density, bed size, eelgrass distribution, and age, weight and size composition, through biosamples, for estimating M and growth. Although horse clams in the low intertidal zone are not part of the "exploitable population", they may affect the stock dynamics of the subtidal population through larval settlement and recruitment mechanisms. Understanding this influence may help in managing the subtidal horse clam stocks. Thus, surveys could extend from the intertidal to the subtidal zones (at least to depths of about 20 m, which are safe for divers). Little is known when horse clams withdraw their siphons from the substrate surface due to physical and or biological factors as has been noted for geoducks (Turner and Cox 1981). Since some horse clam necks may not be visible at any one period this may affect the density estimates of horse clams, therefore show factor estimates (e.g., Campbell *et al.* 1998) should be considered, at

least initially, for these surveys. The time and cost for the surveys, in general, and individual transects by depth, in particular, could be recorded for each survey to assist to help in optimising surveys.

Phase 3, survey evaluation and optimisation phase, should determine the optimal number of beds per area and transects per bed required for future surveys. After 3-5 surveys per area and 3-4 areas have been conducted the data collected could assist in determining the optimal number of beds, transects and biosamples that could be required to make the surveys as efficient and representative as possible. Phases 2-3 could be iterative over a number of years.

4.2. Experimental plots and Adaptive Management

Several long-term experimental plots could be established, at different depths and substrates, to periodically monitor the effects of different rates of exploitation on horse clam recruitment, growth and survival rates. The spatial scale of these areas will depend on a number of factors, including availability of survey resources and sampling sizes required to provide sufficient power to show statistical differences between treatments and or time series changes in the population parameters measured.

5. The "Rotation" Model

Population and fishery persistence requires that the harvested stock retains sufficient amount of spawning stock biomass (SSB) to produce, on average, sufficient amount of offspring to compensate for the loss due to harvesting. The impact of fishing on the average spawning capacity can be measured by spawning stock biomass per recruit (SPR), which is defined as the SSB produced by an average recruit in the whole life-span. To evaluate stock dynamics and management options, we developed a model named "rotation model". The model is an extension of the conventional SPR model (Zhang 1999). It also incorporates uncertainties inherent in scientific knowledge about the status of the population, whereas the conventional SPR model is deterministic.

5.1. Spawning Stock Biomass Per Recruit for an Annual Fishery

When a fishery operates on an annual basis with a fixed fishing mortality rate (F), SPR can be calculated as follows:

$$SPR = \left(\frac{1-e^{-(F+M)}}{F+M}\right) \times \sum_{a=A_r}^{A_{max}} \left(N_a \times e^{-(F+M)(a-A_r)} \times P_a \times W_a\right) \qquad 5.1.1$$

with $N_a = 1$ at $a = A_r$, where a is age, A_r is the age at recruitment, A_{max} is the maximum age, N_a is the number of animals at the beginning of age a, P_a is the proportion of

animals being mature at age a, W_a is the average weight of animals at age a, F and M are instantaneous fishing and natural mortality rates. With a given M, SPR declines monotonically as F increases. The maximum SPR is obtained when F is zero. When recruitment age, longevity and M is fixed, the level of fishing mortality determines the percentage of the maximum SPR the stock is to retain. On the other hand, F can be set once we determine what percentage of the maximum SPR is to be retained by the stock. Conventionally, $F_{x\%}$ (e.g $F_{40\%}$) denotes a fishing mortality rate, which will result in x% (e.g 40%) of the maximum SPR. Translation from percentage of the maximum SPR to percentage of virgin (pristine) SSB relies on the shape of the underlying stock and recruitment relationship (Shepherd 1982, Mace 1994).

5.2. Spawning Stock Biomasss Per Recruit for a Rotation Fishery

A n-year rotation fishery (n = 1, 2, 3 ...) has a fishing cycle of one year of fishing followed by n-1 years of non-fishing. A 1-year rotation fishery is equivalent to an annual fishery. Unlike an annual fishery where recruits from any year experience the same amount of fishing pressure, recruits from different years of a fishing cycle of a multi-year (2 or more) rotation fishery go through different fishing patterns in their whole lifespan. Suppose that we have a 3-year rotation fishery on animals, which recruit to the fishery at age 3. Animals which recruit in a fishing year are susceptible to be harvested when they are 3 years old, 6 years old and so on. Animals which recruit in the next year are susceptible to be harvested when they are 4 years old, 7 years old and so on. Animals which recruit in 2 years after the fishing year are susceptible to be harvested when they are 5 years old, 8 years old and so on. Thus, an average recruit from different years of a fishing cycle produces different amount of SSB. For a n-year rotation fishery, there are n different SPRs (SPR_i, i = 1, 2 ...n) corresponding to n years of a fishing cycle. We measure the impact of fishing on spawning capacity by calculating the average SPR:

$$SPR = \frac{\sum_{i=1}^{n} SPR_i}{n} \qquad 5.2.1$$

To simplify the calculation, we use the following procedure to calculate the average SPR for a n-year rotation fishery. Firstly, let each recruitment contain a constant number of recruits, R, (for the sake of calculation only, no constant recruitment is assumed for the model). Secondly, calculate the equilibrium number of animals at each age before a fishery starts (F=0). Thirdly, calculate the maximum SPR prior to a fishery (F=0). Fourthly, impose a fixed F on the stock and simulate the dynamic change in the number of animals at each age and year forward until the number of animals at each age remain unchanged from one fishing year to another. Lastly, sum up the total SSB present in a whole fishing cycle (composed of n years) and calculate the average SPR by dividing the summed SSB by $n \times R$.

5.3. Required Biological Information

The model requires knowledge on M, growth, ages of animals recruiting to the fishery and longevity, as the conventional yield per recruit and biomass per recruit models. Because this model is stochastic in nature, it also needs information on the variation associated with estimate of M and growth.

All the required information is available for horse clams. Estimates of M, weight from length, and von Bertalanffy model parameters all have associated uncertainties, which are incorporated into the model by simulations. In each simulation, M, weight at a given length, each of the three von Bertalanffy model parameters varied in a normal distribution fashion with the estimated mean and standard deviation or coefficient of variation.

We assumed the horse clam fishery to be a Type 1 fishery (See Ricker 1975, p.10), in which M occurs during a time of year other than the fishing season and the population decreased during the fishing season because of catch removals only. We used Es instead of instantaneous fishing mortality rates (F) in the model, not only because E was more easily comprehended, but E is also more meaningful for a Type 1 fishery. As sizes of horse clams can not be reliably identified prior to removing individuals from the substrate. Exploitation rate (E) for each age of animals also varied in each simulation in a normal distribution fashion with coefficient of variation set arbitrarily to be 0.1 (one third of the coefficient of variation for M). The normal distribution has the defect of not excluding negative values for M and E. To restrict M to a "reasonable" range, M was arbitrarily set to be 30% of the mean or 170% of the mean, if M fell below 30% or rose above 170% of the mean. E was arbitrarily set to be 60% of the mean or 140% of the mean, if E fell below 60% or rose above 140% of the mean.

Recruitment was regarded to occur at an age when horse clams begin to be vulnerable to fishing. Age frequency distribution suggests that *Tresus nuttallii* start to be vulnerable to fishing at age 4 and fully vulnerable at age 7, and *T. capax* start to be vulnerable at age 3 and fully vulnerable at age 4. We assumed vulnerability increased from the age beginning to be vulnerable to the age fully vulnerable to fishing in a stepwise fashion and the increment in vulnerability between any two consecutive ages was the same until an age fully vulnerable to fishing was reached. The mean E on animals younger than fully vulnerable age was adjusted by timing the vulnerability by the mean E for the fully vulnerable animals. The harvested biomass is regarded to be the whole SSB, as the age of maturity approximately coincides with the age of recruitment.

Maximum age was estimated to be 24 years old for *T. nuttallii* and 21 years old for *T. capax* by counting the annuli on the shells (Campbell and Bourne, 2000). However, annuli formed on the margin of shells of old horse clam might not have been entirely enumerated, and older horse clam might not have been sampled. Conservatively, we set maximum age to be 30 years old for both *T. nuttallii* and *T. capax* in the model.

5.4. Mathematical Calculation

We investigated 3 fishing schemes (1-year, 2-year and 3-year rotation fishery), 9 mean natural mortality rates (varying from 0.1 to 0.5 with an interval of 0.05) and 40 exploitation rates (varying from 0.01 to 0.4 with an interval of 0.01). One thousand simulations were carried out for each combination of fishing scheme, natural mortality rate and exploitation rate for each species. Therefore, there are 1080 ($3 \times 9 \times 40$) combinations for each species of horse clam. For simplicity, we describe the calculation procedure just for one combination, which has a n-year rotation fishery (n = 1, 2 or 3), a mean natural mortality rate of M and an exploitation rate of E for animals fully vulnerable to fishing. Calculation procedure is the same for other combinations.

The model assumptions are listed in Table 8, parameters values used by the model in this paper are listed in Table 9 and 10. Some of the symbols, which have been presented in Table 9 or 10, are used here without redundant explanations.

Each recruitment was arbitrarily set to have a constant 10,000 animals. Different number of constant recruits does not affect the final results, as they were expressed in a relative term.

In simulations, natural mortality rate, average length at each age, average weight for a given length and age-specific exploitation rate all vary based on the available information or assumptions.

The natural mortality rate in simulation i (i=1,2…1000), M_i, is:

$$M_i = M + \varepsilon_M \qquad 5.4.1$$

where M is the mean natural mortality rate and ε_M is a random variable generated from a normal distribution with mean of zero and a standard deviation of $\mathrm{cov}_M \times M$. M_i is then set to be $M_{\min}$ or $M_{\max}$, if it is less than $M_{\min}$ or larger than $M_{\max}$:

$$M_i = \begin{cases} M_{\min} & (if \quad M_i < M_{\min}) \\ M_{\max} & (if \quad M_i > M_{\max}) \end{cases} \qquad 5.4.2$$

Average length of animals at age a in simulation i, $\overline{L}_{a,i}$, is calculated based on the von Bertalanffy model, whose parameters vary in a normal distribution fashion:

$$\overline{L}_{a,i} = L_\infty \times \left(1 - e^{-k\left(a - t_0\right)}\right) \qquad 5.4.3$$

where

$$L_\infty^i = L_\infty + \varepsilon_L$$
$$k^i = k + \varepsilon_k$$
$$t_0^i = t_0 + \varepsilon_t$$

where ε_L, ε_k and ε_t are random variables from a normal distribution with mean of zero and a standard deviation of σ_L, σ_k and σ_t respectively.

The average of logarithm of animal weight at age a in simulation i, $\overline{\ln}(W_{a,i})$, is calculated based on average length at age a:

$$\overline{\ln}(W_{a,i}) = \ln A + B \times \ln(\overline{L}_{a,i}) + \varepsilon_w \qquad 5.4.4$$

where ε_w is a random variables from a normal distribution with mean of zero and a standard deviation, *sd*, calculated as follows:

$$sd = S_{xy} \times \sqrt{\frac{1}{ns} + \frac{\left(\ln(\overline{L}_{a,i}) - \overline{\ln}(L)\right)^2}{SS}} \qquad 5.4.5$$

The average weight of animals at age a in simulation i, $\overline{W}_{a,i}$, is obtained as follows:

$$\overline{W}_{a,i} = \exp(\overline{\ln}(W_{a,i})) \qquad 5.4.6$$

Before a fishery starts, the population is assumed to be in an equilibrium state. The number of animals at each age remains unchanged with years. The number of animals at the beginning of age a in simulation i, $N_{a,i}$, is:

$$N_{a,i} = \begin{cases} R & (if \quad a = Ar) \\ N_{a-1,i} \times e^{-M_i} & (if \quad (a > Ar) \end{cases} \qquad 5.4.7$$

where $N_{a-1,i}$ is the number of animals at the beginning of age a-1 in simulation i.

The average number of animals at age a in simulation i, $\overline{N}_{a,i}$, is

$$\overline{N}_{a,i} = \frac{N_{a,i} \times (1 - e^{-M_i})}{M_i} \qquad 5.4.8$$

The maximum spawning stock biomass per recruit in simulation i, $MSPR_i$, is:

$$MSPR_i = \frac{1}{R}\sum_{a=Ar}^{A_{max}} \overline{W}_{a,i} \times \overline{N}_{a,i} \qquad 5.4.9$$

We define the year when a n-year rotation fishery starts as year1. So the fishing year would be year 1, $n+1$, ... $j \times n+1$ (j is a positive integer number). We define the beginning of an year and age as the time fishing starts. We also define that recruitment occurs at the time fishing starts.

Exploitation rate on animals of age a in simulation i, $E_{a,i}$ is:

$$E_{a,i} = E \times Vul_a + \varepsilon_E \qquad 5.4.10$$

where E is the mean exploitation rate for animals fully vulnerable to fishing, Vul_a is the vulnerability of animals at age a to fishing, and ε_E is a random variable from a normal distribution with mean of zero and standard deviation of $\text{cov}_E \times E \times Vul_a$. The vulnerability of animals at age a to fishing is calculated as follows:

$$Vul_a = \begin{cases} \dfrac{a - \text{Asv} + 1}{\text{Afv - Asv} + 1} & (if \quad Asv \le a < Afv) \\ 1 & (if \quad a \ge Afv) \end{cases} \qquad 5.4.11$$

where a is the age of the animals.

$E_{a,i}$ is set to be $E_{\min}$ or $E_{\max}$, if it is less than $E_{\min}$ or larger than $E_{\max}$,:

$$E_{a,i} = \begin{cases} E_{\min} & (if \quad E_i < E_{\min}) \\ E_{\max} & (if \quad E_i > E_{\max}) \end{cases} \qquad 5.4.12$$

Calculation of the number of animals at the beginning of age a in year y in simulation i, $N_{a,y,i}$, depends on the age and whether the previous year (y-1) is a fishing year:

$$N_{a,y,i} = \begin{cases} R & (if \quad a = Ar) \\ N_{a-1,y-1,i} \times (1 - E_{a-1,i}) \times e^{-M_i} & (a \ne Ar, y-1 : fishing) \\ N_{a-1,y-1,i} \times e^{-M_i} & (a \ne Ar, y-1 : non-fishing) \end{cases} \qquad 5.4.13$$

where $N_{a-1,y-1,i}$ is the number of animals at the beginning of age a-1 in year y-1 in simulation i.

The calculation by equation 5.4.13 continues until an equilibrium is reached. At equilibrium the number of animals at each age remains the same from one fishing year to another or from one fishing cycle to another:

$$N_{a,j\times n+1,i} == N_{a,(j+1)\times n+1,i} \qquad 5.4.14$$

where j is a positive integer number, $j\times n+1$ represents a fishing year and $(j+1)\times n+1$ represents the next fishing year.

Calculation of the average number of animals at age a in year y in simulation i, $\overline{N}_{a,y,i}$, depends on whether the current year (year y) is a fishing year:

$$\overline{N}_{a,y,i} = \begin{cases} \dfrac{N_{a,y,i}\times(1-E_{a,i})\times(1-e^{-M_i})}{M_i} & (y: fishing) \\ \dfrac{N_{a,y,i}\times(1-e^{-M_i})}{M_i} & (y: non-fishing) \end{cases} \qquad 5.4.15$$

The average spawning stock biomass per recruit in simulation i, $ASPR_i$,is calculated by dividing the combined biomass by the combined recruits from n recruitments in one fishing cycle:

$$ASPR_i = \sum_{Ar}^{Amax}\sum_{y=j\times n+1}^{j\times n+n}\overline{N}_{a,y,i}\times\overline{W}_{a,i} \Big/ n\times R \qquad 5.4.16$$

where $j\times n+1$ and $j\times n+n$ represent the fishing year and the last non-fishing year respectively in a fishing cycle, after the equilibrium has been reached.

The impact of fishing pattern on the stock in simulation i is examined by calculating the percentage of the maximum spawning stock biomass per recruit, $\%SPR_i$:

$$\%SPR_i = \frac{ASPR_i}{MSPR_i}\times 100 \qquad 5.4.17$$

The calculations are repeated for another simulation until 1000 simulations have been carried out.

5.5 Model Results

The 1000 simulations resulted in 1000 possible consequences, which could be expressed in a frequency distribution fashion. For instance, for a 3-year rotation fishery with E of 10% and M of 0.2, possible percentage of the maximum SPR the stock retains ranged from 66% to 90% with a mean of 78.6% and lower 90% confidence limit of 71.5% (Fig. 3). Mean and lower 90% confidence limit for the percentage of the maximum SPR for various Ms and Es are shown for *T. nuttallii* in Table 11 and 12, and Fig. 4 as a 1-year rotation fishery, Table 13 and 14, and Fig 5 as a 2-year rotation fishery, in Table 15 and 16, Fig. 6 as a 3-year rotation fishery, and for *T. capax* in Table 17 and 18, and Fig. 7 as a 1-year rotation fishery, Table 19 and 20, and Fig 8 as a 2-year rotation fishery, and in Table 21 and 22, Fig. 9 as a 3-year rotation fishery.

The coefficient of variation was positively correlated with E for a given M and rotation (Fig. 10), indicating the variation in percentage of the maximum SPR is higher for higher E values. Thus, more caution is required using high E values in quota determination. For a fixed E and fishing scheme, coefficient of variation varied slightly with M (Fig. 10) and was higher when M was between 0.2-0.3 than when M was smaller or larger than 0.2-.03.

The lower the M, the lower E should be set for each fishing scheme in order to maintain percentage of the maximum SPR at a certain level. When there is a good mixture of the two species, the lower E should be used to avoid possible over-fishing of the other species, as the fishery is not able to discriminate between *T. nuttallii* and *T. capax* prior to removing individuals from the substrate.

A target reference point can be set to a certain percentage of the maximum SPR in the stock. The corresponding E can be set based on the risks we are willing to take. To be precautionary, we may be only willing to take a risk of 10% chance that SSB might fall below the target level. For instance, having 90% chance to retain, at least, 75% maximum SPR in a *T. nuttallii* stock for a 3-year rotation fishery with estimated mean M of 0.2, then E should be set at 8-9%, as suggested by the lower 90% confidence limit. A limit reference point could be set to a lower percentage, for instance, 55% maximum SPR. The status of the fishery could be checked by re-surveys after a fishery has operated for a period. If the limit reference point is being approached, actions would have to be taken to reverse the trend.

To examine the difference in overall exploitation rate, and thus overall catch, for different rotation years, E for 2-year and 3-year rotation fisheries were "standardised" to the E for 1-year rotation fishery by dividing them by 2 and 3 respectively. To maintain the percentage of the maximum SPR at a certain level with a given M, the " standardised" E for 3-year rotation fishery was lower than that for a 2- year rotation fishery, which is lower than E for a 1-year rotation fishery. Higher M or lower percentage of the maximum SPR results in higher inter-rotational differences in overall exploitation rates (Fig. 11).

6. Discussion

The management unit of bivalves is typically either based on individual areas (each having several beds), as for the geoduck fishery, or on individual beds, as for the depuration intertidal clam fishery. As the number of horse clam beds are small, as compared with the number of geoduck beds, horse clams could be managed on the bed-by-bed basis.

T. nuttallii almost exclusively live subtidally, while *T. capax* live both intertidally and subtidally. In most subtidal horse clam beds, *T. nuttallii* and *T. capax* co-exist with a varying degree of mixture. When there is a good mixture of the two species, the lower E should be used to avoid possible over-fishing of the other species, as the fishery is not able to discriminate between these two species prior to removing individuals from the substrate. The other ecological concerns are the potential impacts of horse clam fishery on eelgrass beds and geoduck stocks

Eelgrass beds support herring spawning (Haegle and Miller 1979) and possibly provide a good habitat for horse clams (Wendell et. al. 1976). They must be adequately protected. The extent of eelgrass distribution appear to vary in different areas. No eelgrass presence was recorded in Morfee/Dunlap area from the geoduck surveys. Eelgrass was found to be present as deep as 4.5 m in Anderson Island, 6-7 m in Hotspring Island and Kettle Inlet, 7-8 m in Anderson Island and Elbow Bank, 8-9 m in Epper Pass and Yellow Bank, and 14-15 m in Cumshewa Inlet in the geouck surveys. The late 1970s survey (Haegele and Hamey 1979, Haegele and Miller 1979) seemed to reveal that a substantial amount of eelgrass was present below 3.5 m in the Meares Island section of Clayoquot Sound. The current depth restriction for horse clam fishing is only 10 feet (3.06 m) below chart datum, which does not appear to be adequate enough in most of the areas.

Caution is required in interpreting eelgrass distribution from geoduck survey data since these surveys did not measure the full extent of eelgrass beds and shallow subtidal and deep intertidal areas, where eelgrass beds were abundant, could have been avoided. Furthermore, the geoduck surveys only recorded presence/absence of eelgrass in each surveyed quadrat. Therefore, eelgrass density distribution could not be adequately evaluated using the data from the geoduck surveys. The shortcoming of the late 1970s survey is that the sampling size was too small in the deep water, as percentage coverage of eelgrass was recorded from only 7 quadrats between 3.5 and 7 m. The adequacy of the current horse clam depth restriction has yet to be assessed in light of quantified data on eelgrass distribution from future surveys. If we are to restrict the fishery to a depth, below which there is only marginal amount of eelgrass, (say 10%), we need to record the percentage of eelgrass coverage in each sampling quadrat to a sufficient depth in future surveys, allowing comparison between the distribution and density of horse clams and eelgrass at depth.

A considerable number of horse clams, which may occur in the shallow waters in many areas without eelgrass, may be protected from harvesting by the current 10 ft depth restriction. The fishery depth restriction may reduce the risks of recruitment overfishing as these areas may act as refuges for brood stock. As they are part of the integral subtidal horse clam population, their biomass should be surveyed and in some shallow areas which are clearly without eelgrass beds could be considered as part of the total biomass for setting quota.

Horse clam distribution appears to overlap geoduck distribution. The detrimental effect caused by horse clam exploitation on geoduck population, and vice versa, is unknown. Consequently, the effect of horse clam harvesting on geoduck population should be considered. A 3-year rotation fishery may be less detrimental than an annual one to both geoduck and horse clam populations. However, when we opt for a 3-year rotation fishery, the standardised E (E/3) would be less than the E for an annual fishery to maintain the same percentage of the maximum SPR. For instance, to maintain the percentage of the maximum SPR at 60%, the standardised E for a 3-year rotation would be about 7% or 11% lower than the E for an annual fishery, when the M is 0.1 or 0.3. Thus, yield would also be reduced accordingly. To choose a fishing scheme, the managers have to weigh the effect of possibly reducing the detrimental damage over the effect of sacrifice of some yield for a multi-year rotation fishery.

The rotation model translates the available information on M, growth and age-based vulnerability into a management decision rule. The model is also valuable in converting the uncertainty inherent in scientific knowledge about the status of the fish population into estimates of biological risk. Management options can be taken based on the degree of risks managers are willing to take. However, a word of caution has to be stressed here. The model-predicted probability for possible consequences caused by a management action can not be taken too literally. This is only correct, if the stock behaves exactly as assumed and described by the model. Surely, this is not the case. Stock dynamics are regulated by many complex factors, most of which are unknown. The model only tries to describe and predict the general behaviour of the population based on limited amount of knowledge and some assumptions.

To choose a proper E, we need to answer the question: what percentage of the maximum SPR the stock should be retained in order to have a viable and sustainable fishery? To answer this question well, ideally we need to know how resilient the stock is to fishing or what is the threshold replacement level. A threshold replacement level is defined as the percentage of the maximum SPR, at which successive generations can just, on average, replace each other without surplus production. The lower this threshold level, the higher the resilience of the stock to fishing. In United States, this threshold replacement level is used as a reference point for defining overfishing for 60% of the stocks under the U.S. Federal management (Mace and Sissenwine 1993). When the percentage of the maximum SPR falls below this level, the stock is considered to be over-fished. The levels chosen to represent overfishing by the U.S Fisheries Management Councils have often been somewhat arbitrary, ranging anywhere from 5-70%, although usually falling within the range 20-35% (Mace and Sissenwine 1993). Goodyear (1989) suggested that this threshold level should be assumed to be, at least, 20% of the

maximum SPR, when the spawning and recruitment relationship can not be determined. Mace and Sissenwine (1993) estimated the threshold replacement levels for various kinds of fin-fish and one invertebrate species, Atlantic sea scallops (*Placopecten magellanicus*), by analysing spawning-recruitment data together with SPR modelling. They found that the threshold replacement levels ranged from 2 to 65.4% with a mean of 18.7%. The threshold replacement level for the Atlantic sea scallops was found to be only 2.8%. Frequency distribution of the threshold replacement levels was highly skewed towards the lower level. More than 80% of them was estimated to be below 30%. Therefore, Mace and Sissenwine (1993) suggested that the default threshold replacement level should be 30%, when there is no other means to estimate this level.

Based on simulations on stock-recruitment relations of a variety of groundfish, Clark (1993) proposed that a target reference point can be set to $F_{40\%}$, a fishing rate which will produce a SPR being 40% of the maximum. Mace (1994) also recommend to use $F_{40\%}$ as a target fishing rate for fin-fish, when stock and recruitment relationship is unknown. In fact, recommendations were recently made to set fishing mortality rate to be $F_{40\%}$ for geoduch fishery in Washington, based on the stock assessment paper by Bradbury et. al (1998).

Considerable precaution is required for a new and developing fishery, as the resilience of the stock is poorly understood. One of the most important management measures for new and developing invertebrate fisheries is early control of fishing capacity (Perry *et al.* 1999). Thus, we suggest that the limit reference point be set, at least, to 60% of the maximum SPR and the target reference point be set, at least, to 80% of the maximum SPR. Experimental plots could be established to test the impacts of alternative Es on the population. For some beds, E corresponding to the target reference point and based on the lower 90% confidence limit might be applied. For another set of beds, E corresponding to the target reference point but based on the mean value be used. Some other beds may serve as a control with zero exploitation rate. The stock dynamics of these experimental beds should be monitored. The knowledge out of this experimental study should enable us to refine Es.

The limit reference point must in no way be regarded as a reference point the fishery may approach or even reach. Action must be taken, as soon as there is evidence that the fishery is approaching the limit reference point. In the developing (fishing-down) period, large aggregations are rapidly being reduced and fishermen's fishing experience and efficiency increase quickly. The fishery position relative to the target reference point and limit reference point based on the CPUE data is difficult to check. Therefore, the bed should be re-surveyed, after the fishery has operated for a period, to assess the impact of the fishery on the stock.

Determining a total allowable catch (TAC) requires information on biomass and setting up an exploitation rate, which requires information on M, growth, ages of animals recruiting to the fishery and longevity to calculate exploitation rates. Although these parameters have been estimated from some areas, there are probably considerable geographical variations in some of

the parameters, especially M. Thus, estimates of parameters obtained from one area should not be extrapolated to another, unless such extrapolation could be well justified.

M varies greatly for the same horse clam species in different areas and for different horse clam species in the same area. Although growth is also variable in different areas, the effect of the known possible range of variation in growth on the consequences to the stock dynamics is much smaller than the effect of the known possible variation in M. Use of different growth models established for *T. nuttallii* and same E ranging from 1 to 40% only results in a difference less than $\pm$ 2% of the maximum SPR for a 3-year rotation fishery. In contrast, use of the growth models for *T. nuttallii* in Lemmens Inlet and an E ranging from 10-20% resulted in a reduction in the percentage of the maximum SPR by 7.6-12.4% for a 3-year rotation fishery, when M was decreased from 0.352 as in Comox Bar to 0.2 as in Klaskino Inlet. Knowing what M is dictates to a great extent what level of E should be set. Estimation of M has a higher priority than estimation of growth. When estimation is uncertain, choosing a lower M is more conservative and precautionary, as the E will decrease according to the model.

Due to the stochastic nature of fish populations, there are almost always uncertainties associated with parameter estimates. Whenever possible, variations should also be estimated, as demonstrated by Campbell *et al.* (1990) and Campbell and Bourne (2000). This will allow the uncertainties to be appropriately incorporated in the calculations of Es.

Ages of animals recruiting to the fishery was estimated in this paper based on the age frequency distribution derived of the field studies in Ritchie Bay and Seal Islet by Campbell and Bourne (2000). This parameter should also be examined and refined, during the survey and subsequent fishery, especially when there is a change in fishing technology or techniques.

The longevity was conservatively set to be 30 years for both *T. capax* and *T. nutallii*, although the oldest *T. capax* and *T. nutallii* were estimated to be 21 and 24 years respectively. The longevity should be kept as 30 years for running the model, unless there is evidence that they could live even longer.

In short, parameters which should be estimated before a fishery are biomass (density and bed size) M and growth. Size and age at recruitment to the fishery should be examined, either at the surveying stage or soon after a fishery has started. Stock and recruitment relationships should also be investigated, whenever there is an opportunity, as this knowledge provides a biological basis for setting target and limit reference points. In addition, the impact of spatial aggregation on the stock dynamics should be studied.

Schnute and Richards (1997) and Schnute et. al. (1999) developed an analytical model to derive various kinds of biological reference points useful for setting target and limit reference points. The biological parameters required of this model are recruitment age, the parameters of von Bertalanffy equation, length and weight equation, natural mortality rate, and the resilience ratio, ϕ:

$$\phi = \frac{R_0 / S_0}{R^{'} / S^{'}}$$

where R_0 is the recruitment at virgin spawning biomass, S_0, $R^{'}$ is the recruitment when spawning biomass is close to zero, and $S^{'}$ is the spawning biomass close to zero. With an assumption that stock and recruitment relationship can be described by Beverton-Holt or Ricker stock recruitment model, this analytical model can produce biological reference points such as harvest rate, catch, biomass, average age and average weight corresponding to MSY. In addition, the model could also yield information on harvest rate corresponding to a certain percentage (e.g, 50%) reduction in the spawner-recruit ratio (S/R) from the pristine value S_0 / R_0.

The parameters required of this analytical model are available for horse clams except for ϕ. If we assume a value for ϕ and a stock recruitment relationship for horse clam stocks, we could use this model to derive biological reference points which might help us in setting target and reference points. Comparison of the mean length from the market and field-survey samples with the calculated mean length corresponding to MSY might indicate where the current stock is standing.

7. Recommendation

Surveys should be carried out to determine required biological information such as density, bed size, M, growth and possibly age at recruitment prior to a directed fishery on horse clams in particular beds. Percentage of eelgrass coverage at different depth ranges and overlap distribution of horse clams and geoducks should also be investigated. The limit reference point should be set, at least, to 60% of the maximum SPR and the target reference point be set, at least, to 80% of the maximum SPR. Where possible experimental adaptive management of some plots or beds should be conducted to examine the response of the horse clam populations to different exploitation rates.

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Table 1. Subtidal species composition of horse clam in B.C.

Area	Year	Collection sample Method	Number	*Percent of* *T. nuttallii*	*T. capax*	Source
Comox Bar	1983	Commercial	195	42.1	57.9	Bourne and Harbo (1987)
Epper Pass	1990	Commercial	123	76.4	23.6	Harbo (unpublished data)
Klaskino Inlet	1993	Commercial	296	>99	<1	Campbell and Bourne (2000)
Lemmens Inlet	1989	Commercial	783	78.3	21.7	Campbell (1989)
Newcastle Island	1989	Commercial	103	100	0	Campbell (1989)
Ritchie Bay	1993	Biosample	511	99.2	0.8	Campbell and Bourne (2000)
Seal Islets	1993	Biosample	602	0.5	99.5	Campbell and Bourne (2000)
Stubbs Island	1983	Commercial	93	93.5	6.5	Bourne and Harbo (1987)
Yellow Bank	1990	Commercial	125	76	24	Harbo (unpublished data)

Table 2. Percentage of geoduck and horse clam in different depth range. (Number is the total number of observed animals in the entire depth range presented. (C. Hand Unpublished data)

Species	Depth Range (m)	Ahousat	Anderson Island	Cumshewa Inlet	Duncan Island	Elbow Bank	Hotspring Island	Kettle Inlet	Morfee/ Dunlap	N. Epper Pass	Yellow Bank
Geoduck	0-3	1.28	3.15	0.48	1.53	6.02	4.56	1.32		2.00	2.00
	3-6	2.86	9.16	10.65	6.80	21.20	11.86	4.84		9.19	9.19
	6-9	4.33	21.32	17.80	11.41	13.59	20.95	7.82	9.70	8.48	8.48
	9-12	22.71	12.88	47.76	19.00	18.89	23.19	22.30	19.79	18.04	18.04
	12-15	35.19	18.17	22.17	25.78	18.06	39.44	22.86	31.63	27.96	27.96
	15-18	33.62	35.32	1.14	35.48	22.24		40.87	38.88	34.32	34.32
	Number	9693	15465	4579	12816	2629	11801	11740	2980	1303	6325
Horse Clam	0-3	48.47	12.01	2.35	9.72	43.11	32.90	5.88		21.26	21.26
	3-6	21.07	15.16	26.52	25.39	26.46	16.23	18.83		25.29	25.29
	6-9	2.50	15.41	20.68	12.78	14.04	23.62	7.50	28.67	21.09	21.09
	9-12	6.97	14.48	44.61	15.60	7.65	18.77	29.76	23.58	15.30	15.30
	12-15	6.79	4.06	5.84	13.11	3.62	8.47	14.93	30.51	11.34	11.34
	15-18	14.20	38.87	0.00	23.40	5.13		23.11	17.24	5.72	5.72
	Number	499	109	970	487	1412	1278	248	1540	400	1273

Table 3. Length frequency distribution for horse clam samples in B.C.

Area	Year	Collection Sample Method	Species	Number	Shell length (mm) Mean	Range	Standard Deviation	Source
Comox Bar	1983	Commercial	*T. nuttallii*	82	158.2	140-188	12.2	Bourne and Harbo (1987)
			T. capax	114	156.2	132-192	10.8	
Epper Pass	1990	Commercial	*T. nuttallii*	94	167	97-192		Harbo (unpublished data)
			T. capax	29	171	154-185		
Klaskino Inlet	1993	Commercial	*T. nuttallii*	332	176			Campbell and Bourne (2000)
Lemmens Inlet	1989	Commercial	*T. nuttallii*	490	170.2	73--207	21.6	Campbell (1989)
			T. capax	203	137	54-161	16.2	
Lemmens Inlet	1989	Biological	*T. nuttallii*	72	167	96-195	20.4	Campbell (1989)
			T. capax	34	136.4	65-178	21.7	
Morfee Island	1988	Commercial	Horse Clam	372	159.8	99-197		Harbo and Hobbs (1989)
Newcastle Island	1989	Commercial	*T. nuttallii*	103	144	93-191	15.4	Campbell (1989)
Ritchie Bay	1993	Biological	*T. nuttallii*	507	159			Campbell and Bourne (2000)
Seal Islets	1993	Biological	*T. capax*	599	113			Campbell and Bourne (2000)
Stubbs Island	1983	Commercial	*T. nuttallii*	87	163.2	135-190	10.4	Bourne and Harbo (1987)
			T. capax	6	149.8	138-169	11.3	
Yellow Bank	1990	Commercial	*T. nuttallii*	95	171	130-194		Harbo (unpublished data)
			T. capax	30	174	154-194		

Table 4. Estimates of natural mortality rates (M) for subtidal horse clams in B.C.

Area	Year	Method Sample of Collection	Species	Natural mortality	95% confidence interval	Approximate Standard Deviation	Source
Comox Bar	1983	Commercial	*T. nuttallii*	0.352			Harbo (unpublished data)
Klaskino Inlet	1993	Commercial	*T. nuttallii*	0.2	0.06-0.33	0.0675	Campbell and Bourne (2000)
Ritchie Bay	1993	Biological	*T. nuttallii*	0.44	0.26-0.63	0.0925	Campbell and Bourne (2000)
Stubbs Island	1983	Commercial	*T. nuttallii*	0.613			Harbo (unpublished data)
Comox Bar	1983	Commercial	*T. capax*	0.475			Harbo (unpublished data)
Seal Islets	1993	Biological	*T. capax*	0.16	0.05-0.26	0.0525	Campbell and Bourne (2000)

Table 5. Growth models for some subtidal horse clam populations in B.C.

a. parameters of von Bertalanffy equation (values in brackets are approximate 95% confidence intervals).

b. length (L) and total wet drained weight (W) relationship: ln(W) = lnA+B*ln(L)

a. von Bertalanffy equation

Area	Year	Method of Collection	Species	Linf	k	t_0	Sorce
Klaskino Inlet	1993	Commercial Sample	*T. nuttallii*	231 (± 6)	0.116 (± 0.01)	-0.5 (± 0.23)	Campbell and Bourne (2000)
Lemmens Inlet	1989	Commercial Sample	*T. nuttallii*	202 (± 3)	0.167 (± 0.006)	0.5 (± 0.05)	Campbell *et. al.* (1990)
Newcastle Island	1989	Commercial Sample	*T. nuttallii*	183 (± 5)	0.168 (± 0.012)	0.51 (± 0.1)	Campbell *et. al.* (1990)
Ritchie Bay	1993	Biological Sample	*T. nuttallii*	200 (± 13)	0.139 (± 0.024)	-0.15 (± 0.33)	Campbell and Bourne (2000)
Lemmens Inlet	1989	Commercial Sample	*T. capax*	195 (± 7)	0.154 (± 0.016)	-0.01 (± 0.18)	Campbell and Bourne (2000)
Seal Islets	1993	Biological Sample	*T. capax*	192 (± 5)	0.148 (± 0.013)	-0.13 (± 0.22)	Campbell and Bourne (2000)

b. Length and weight ralationship

Area	Year	Method of Collection	Species	lnA	B	Source
Klaskino Inlet	1993	Commercial Sample	*T. nuttallii*	-9.743	3.185	Campbell and Bourne (2000)
Lemmens Inlet	1989	Commercial Sample	*T. nuttallii*	-10.029	3.219	Campbell *et. al.* (1990)
Newcastle Island	1989	Commercial Sample	*T. nuttallii*	-9.31	3.087	Campbell *et. al.* (1990)
Ritchie Bay	1993	Biological Sample	*T. nuttallii*	-10.115	3.213	Campbell and Bourne (2000)
Lemmens Inlet	1989	Commercial Sample	*T. capax*	-10.167	3.289	Campbell and Bourne (2000)
Seal Islets	1993	Biological Sample	*T. capax*	-9.125	3.084	Campbell and Bourne (2000)

Table 6. Percentage of quadrat with eelgrass at different depth ranges. (N=Number quadrats, %=percentage of quadrats with eelgrass).

Depth Range (m)	Ahousat		Anderson Island		Cumshewa Inlet		Elbow Bank		Hotspring Island		Kettle Inlet		North Epper Pass		Yellow Bank	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
0-1	3	0.0	19	21.1	23	8.7	13	100.0	49	4.1	27	11.1	7	100.0	1	100.0
1-2	6	16.7	19	52.6	28	32.1	10	100.0	61	11.5	24	4.2	3	100.0	5	100.0
2-3	11	27.3	53	34.0	29	27.6	7	100.0	89	9.0	67	10.4	6	100.0	18	94.4
3-4	12	16.7	44	31.8	56	26.8	9	55.6	101	7.9	67	10.4	6	16.7	24	75.0
4-5	17	17.6	61	3.3	68	16.2	43	46.5	98	6.1	78	5.1	7	28.6	25	24.0
5-6			63	1.6	80	17.5	22	13.6	72	5.6	76	5.3	11	18.2	19	0.0
6-7			66	0.0	95	6.3	24	8.3	81	1.2	98	2.0	28	0.0	30	0.0
7-8			114	2.6	108	0.0	47	6.4					13	0.0	23	4.3
8-9					87	0.0							27	14.8	28	3.6
9-10					80	3.8										
10-11					76	2.6										
11-12					98	2.0										
12-13					80	8.8										
13-14					67	0.0										
14-15					56	1.8										

Table 7. Percentage of eelgrass coverage for the quadrats dominated by eelgrass at different depth ranges in the Meares Island Section of Clayoquot Sound

Depth Range (m)	% of eelgrass coverage	Number quadrats
0.1 - 0.5	30	2
0.6 - 1	53	18
1.1 - 1.5	58	19
1.6 - 2	57	11
2.1 - 2.5	59	10
2.6 - 3	50	3
3.1 - 3.5	38	5
3.6 - 4	60	1
4.1 - 4.5	25	2
4.6 - 5	20	2
5.1 - 5.5	10	1
5.6 - 6	60	1

Table 8. Assumptions for the rotation model

1) The fishery is a type 1 fishery (Ricker 1975). Natural mortality occurs during a time of year other than the fishing season. The population decreases during the short fishing season because of catch removals only.
2) Growth is not affected by fishing. Growth follows the Von Bertalanfy model with model parameters variations independent from each other.
3) Recruitment occurs in a knife-edge fashion at the time fishing begins.
4) All recruited animals experience the same natural mortality rate.
5) Exploitation rate increases in a step-wise fashion from the age beginning to be vulnerable to the age fully vulnerable to fishing.
6) Exploitation rate varies between different age classes in a normal distribution fashion between a set minimum and maximum rate.
7) All animals above the maximum age are dead.

Table 9. Parameters used for the rotation model for *T. nuttallii*

R,	Annual Recruit	10000	
n,	Years of Rotation		1, 2, 3 years
Amax,	Longevity		30 years old
Ar,	Age of recruitment		4 years old
M,	Natural Mortality		0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4
S_{xy},	Coefficient of variation for M	0.3	
Mmin,	Minimum M		$0.3 \times M$
Mmax,	Maximum M		$1.7 \times M$
E,	Exploitation rate		0.01, 0.02... 0.4
cov_E,	Coefficient of variation for E		0.1
Vul_a	Vulnerability of age a to fishing		
Emin,	Minimum E		$0.6 \times E \times Vul_a$
Emax,	Maximum E		$1.4 \times E \times Vul_a$
Asv,	Age starting to be vulnerable to fishing		4
Afv,	Age starting to be fully vulnerable to fishing		7

Von Bertalanfy Equation parameters

L_∞		202
σ_L,	Standard deviation for L_∞	1.5
k		0.167
σ_k,	Standard deviation for k	0.003
t_o		0.5
σ_t,	Standard deviation for t_o	0.025

Parameters for calculating Weight (W) from Length (L)

$\ln(W) = \ln A + B \times \ln(L)$

lnA		-10.029
B		3.219
S_{xy},	Standard error of estimate	0.118
ns,	Number of samples for the estimation	146
$\overline{\ln}(L)$,	Mean of *ln(L)* from the sample	4.815
SS,	Sum of squares of *ln(L)*: $\sum(\ln(L_i) - \overline{\ln}(L))^2$	29.096

Table 10. Parameters used for the rotation model for *T. capax*

R,	Annual Recruit	10000	
n,	Years of Rotation		1, 2, 3 years
Amax,	Longevity		30 years old
Ar,	Age of recruitment		3 years old
M,	Natural Mortality		0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4
cov_M,	Coefficient of variation for M	0.03	
$Mmin$,	Minimum M		$0.3 \times M$
$Mmax$,	Maximum M		$1.7 \times M$
E,	Exploitation rate		0.01, 0.02... 0.4
cov_E,	Coefficient of variation for E		0.01
Vul_a	Vulnerability of age a to fishing		
$Emin$,	Minimum E		$0.6 \times E \times Vul_a$
$Emax$,	Maximum E		$1.4 \times E \times Vul_a$
Asv,	Age starting to be vulnerable to fishing		3
Afv,	Age starting to be fully vulnerable to fishing		4

Von Bertalanfy Equation parameters

L_∞		195
σ_L,	Standard deviation for L_∞	3.5
k		0.154
σ_k,	Standard deviation for k	0.008
t_o		-0.01
σ_t,	Standard deviation for t_o	0.09

Parameters for calculating Weight (W) from Length (L)
$\ln(W) = \ln A + B \times \ln(L)$

lnA		-9.865
B		3.29
S_{xy},	Standard error of estimate	0.227
ns,	Number of samples for the estimation	73
$\overline{\ln(L)}$,	Mean of $ln(L)$ from the sample	4.835
SS, Sum of squares of $ln(L)$: $\sum(\ln(L_i) - \overline{\ln(L)})^2$		3.474

Table 11. Average percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 1-year rotation fishery on *T. nuttallii*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	90.0	91.6	93.0	94.0	95.0	95.6	96.1	96.6	97.0
0.02	81.2	84.1	86.6	88.6	90.4	91.6	92.6	93.5	94.1
0.03	73.3	77.6	80.9	83.7	85.9	87.6	89.3	90.3	91.5
0.04	66.6	71.7	75.5	79.3	81.7	84.4	86.0	87.9	88.9
0.05	60.7	66.2	71.1	74.6	78.1	80.8	83.1	85.0	86.6
0.06	55.3	61.3	66.6	71.1	75.0	78.0	80.8	82.5	84.4
0.07	50.8	57.6	62.9	67.3	71.6	75.0	77.5	79.7	81.7
0.08	46.6	53.2	59.5	64.4	68.7	72.1	75.3	77.9	80.3
0.09	43.2	50.1	56.0	61.2	65.7	69.9	73.1	75.9	77.6
0.1	39.6	46.5	53.1	58.3	63.3	67.4	70.5	74.0	76.0
0.11	37.1	44.1	50.6	55.7	60.9	65.3	68.5	72.3	74.8
0.12	34.1	41.1	47.8	53.7	58.8	62.6	67.5	69.7	72.5
0.13	31.9	39.0	45.6	51.4	56.4	60.5	65.3	68.2	71.3
0.14	29.5	36.7	43.5	49.7	54.0	58.4	63.3	66.6	69.1
0.15	27.8	34.7	41.5	47.3	52.6	57.4	61.7	65.2	67.4
0.16	26.2	32.5	39.2	45.3	51.1	55.4	59.0	62.9	66.5
0.17	24.3	31.5	37.4	43.4	49.3	54.0	57.6	61.8	64.6
0.18	22.8	29.7	35.6	42.3	47.7	52.1	56.1	60.5	63.6
0.19	21.8	28.2	34.3	40.8	45.8	50.4	55.4	59.3	62.2
0.2	20.5	26.9	33.2	39.2	44.7	49.4	53.6	58.1	61.2
0.21	19.4	25.7	32.0	37.7	42.9	48.2	53.2	56.1	59.7
0.22	18.4	24.6	30.7	36.6	42.6	47.0	51.2	54.7	58.6
0.23	17.5	23.7	29.7	35.4	41.1	45.4	50.1	53.9	57.0
0.24	16.6	22.3	28.3	34.2	39.2	44.3	48.7	52.7	56.6
0.25	15.8	21.5	27.3	32.9	38.5	43.4	47.4	52.1	55.6
0.26	15.0	21.0	26.5	32.1	37.3	42.1	46.8	51.0	55.3
0.27	14.3	20.0	25.5	31.3	36.3	40.8	45.7	49.7	53.7
0.28	13.8	19.1	24.8	30.2	35.9	40.3	44.9	48.4	52.5
0.29	13.1	18.0	23.9	29.6	34.2	39.0	43.8	47.5	51.3
0.3	12.5	18.0	23.2	28.3	33.4	38.1	42.8	46.6	50.7
0.31	12.2	17.0	22.2	27.6	32.5	37.4	41.4	45.9	49.3
0.32	11.5	16.7	21.9	27.0	31.6	36.2	40.4	44.5	48.9
0.33	11.1	16.1	21.0	25.8	30.7	36.0	40.4	43.9	47.9
0.34	10.7	15.3	20.3	25.5	30.4	34.8	39.3	43.6	47.2
0.35	10.3	14.9	19.6	24.7	29.6	34.3	38.8	43.0	46.7
0.36	10.0	14.5	19.3	24.5	28.4	33.9	38.0	41.0	45.5
0.37	9.7	13.9	18.6	23.2	28.7	33.0	37.4	41.2	45.0
0.38	9.2	13.5	18.3	23.0	27.7	32.4	36.7	41.0	44.4
0.39	9.0	13.2	18.0	22.5	26.9	31.0	36.0	40.7	43.7
0.4	8.7	12.8	17.1	22.2	26.7	30.9	35.3	38.9	43.4

Table 12. Lower 90% confidence limit of percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 1-year rotation fishery on *T. nuttallii*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	88.2	89.3	90.4	91.3	92.3	93.0	93.6	94.3	94.9
0.02	78.1	79.9	81.7	83.6	85.4	86.7	87.8	89.1	89.7
0.03	69.1	71.9	74.4	76.6	79.0	80.9	83.1	84.4	85.4
0.04	61.3	64.8	67.3	71.0	73.0	76.3	77.8	80.5	81.4
0.05	54.9	58.5	62.0	64.7	67.8	70.7	73.7	76.2	77.6
0.06	49.1	52.5	56.4	60.3	64.2	67.4	70.3	72.5	74.5
0.07	44.2	48.3	52.2	55.7	60.1	62.8	65.5	68.2	70.1
0.08	39.7	43.6	48.1	52.2	56.1	59.0	62.6	65.7	68.2
0.09	36.0	40.1	44.5	48.0	52.6	56.3	60.1	62.9	64.1
0.1	32.7	36.5	41.3	44.6	49.1	53.2	56.2	61.0	62.3
0.11	29.9	34.3	38.4	41.7	46.9	50.8	54.0	58.7	61.2
0.12	26.9	30.9	35.3	39.4	44.0	46.9	53.1	54.7	57.7
0.13	25.0	29.0	32.5	36.7	41.2	44.8	49.8	53.0	55.9
0.14	22.7	26.8	30.8	35.6	38.5	42.6	46.9	50.7	53.1
0.15	21.0	24.6	28.8	32.3	37.8	41.3	45.8	48.8	50.3
0.16	19.6	22.5	26.3	31.2	36.0	38.8	41.8	46.5	48.9
0.17	17.7	21.6	24.8	28.8	33.2	37.5	39.7	44.9	47.3
0.18	16.5	19.8	23.2	27.4	31.8	35.5	39.1	43.2	46.9
0.19	15.6	19.1	21.8	26.4	29.7	33.5	38.1	42.7	44.5
0.2	14.6	17.3	21.0	25.2	29.0	32.1	35.6	40.0	43.4
0.21	13.5	16.6	19.8	23.5	27.0	31.5	35.8	38.0	41.8
0.22	12.8	15.4	18.5	22.4	26.7	30.1	33.8	36.1	40.7
0.23	11.9	14.6	17.8	21.5	25.5	28.1	32.0	36.2	38.1
0.24	11.1	13.4	16.5	20.4	24.3	27.5	31.1	34.9	37.8
0.25	10.4	12.9	16.1	19.0	23.1	27.0	30.0	33.7	37.5
0.26	9.7	12.6	15.7	18.7	21.6	25.2	29.2	33.1	37.7
0.27	9.2	11.6	14.4	17.8	20.7	23.6	28.5	32.2	35.4
0.28	8.9	11.3	14.1	16.9	20.6	23.2	27.0	30.4	33.9
0.29	8.5	10.0	12.9	16.6	18.6	22.2	26.3	28.2	32.0
0.3	7.9	10.2	12.5	15.3	18.4	21.2	25.7	27.6	32.0
0.31	7.7	9.4	11.6	14.8	17.8	21.1	24.1	27.8	30.7
0.32	7.1	9.1	11.6	14.3	16.9	19.6	22.6	26.0	30.1
0.33	6.8	8.8	10.5	13.3	16.3	19.7	23.5	25.4	29.2
0.34	6.3	8.4	10.3	12.7	15.9	18.9	22.1	25.4	28.9
0.35	6.3	8.1	10.2	12.5	14.7	18.4	21.8	24.6	28.0
0.36	6.0	7.6	9.7	12.4	14.2	18.0	21.7	23.0	26.4
0.37	5.8	7.4	9.3	11.3	15.1	17.2	20.6	22.9	26.0
0.38	5.4	7.1	9.2	11.9	13.7	16.9	20.4	23.4	25.8
0.39	5.3	6.7	8.9	11.0	13.2	15.8	18.9	23.2	25.3
0.4	5.0	6.6	8.2	10.9	12.9	15.6	18.8	21.6	24.5

Table 13. Average percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 2-year rotation fishery on *T. nuttallii*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	94.7	95.6	96.3	97.0	97.3	97.7	98.0	98.3	98.5
0.02	89.8	91.3	92.9	94.0	94.8	95.6	96.0	96.6	97.0
0.03	85.0	87.6	89.5	91.2	92.7	93.4	94.4	95.0	95.5
0.04	80.5	84.0	86.2	88.5	90.1	91.2	92.5	93.5	94.2
0.05	76.4	80.3	83.5	85.9	87.8	89.3	90.8	91.9	92.9
0.06	72.6	77.3	80.5	83.4	85.8	87.6	89.1	90.2	91.5
0.07	69.0	73.8	77.7	81.1	83.4	85.4	87.3	89.0	90.2
0.08	65.7	70.6	75.3	78.7	81.5	84.0	86.1	87.3	88.9
0.09	62.3	68.1	72.5	76.1	79.7	82.1	84.3	85.9	87.3
0.1	59.5	65.5	70.4	74.4	77.8	80.7	82.7	84.5	86.2
0.11	56.5	62.6	67.9	72.4	75.9	78.9	81.3	83.8	85.1
0.12	54.0	60.1	66.0	70.6	74.4	77.2	80.3	82.2	84.2
0.13	51.5	57.8	63.9	68.4	73.1	75.5	78.5	80.7	82.9
0.14	49.3	56.1	61.8	66.5	71.1	74.3	77.2	79.5	81.6
0.15	47.1	53.7	59.8	65.3	69.3	72.6	76.2	78.1	80.6
0.16	44.9	51.3	57.9	63.7	67.9	71.4	74.6	77.5	79.7
0.17	42.9	49.9	56.2	61.7	66.4	70.7	73.8	76.2	78.5
0.18	41.0	48.3	54.6	60.1	65.1	68.9	72.3	75.5	77.3
0.19	39.4	46.7	52.7	58.5	63.4	68.1	71.4	74.1	76.5
0.2	37.9	45.1	51.8	57.0	62.1	66.3	70.0	72.8	75.5
0.21	36.3	43.3	49.7	55.8	60.9	65.0	69.1	71.4	74.6
0.22	34.8	41.6	49.0	54.2	59.5	63.9	67.5	70.3	73.3
0.23	33.3	40.7	47.3	53.5	58.5	62.4	66.6	69.2	72.4
0.24	32.0	39.7	46.5	51.6	57.0	61.8	65.2	68.4	71.5
0.25	30.7	37.9	44.6	50.6	56.1	60.3	64.2	67.8	70.9
0.26	29.7	36.3	43.6	49.8	54.8	59.9	63.5	67.2	70.1
0.27	28.8	35.6	42.3	48.1	53.2	58.2	62.4	65.6	69.0
0.28	27.3	34.0	41.2	47.3	52.7	57.3	61.4	64.6	67.8
0.29	26.6	33.6	40.4	46.3	51.2	56.4	60.9	64.2	66.6
0.3	25.3	32.6	39.1	45.7	50.4	55.2	59.3	63.4	66.3
0.31	24.6	31.6	38.1	44.2	49.8	54.5	58.7	62.5	65.2
0.32	23.5	30.8	37.3	43.4	48.5	53.3	58.2	61.8	65.3
0.33	23.0	29.7	36.7	42.1	47.5	52.8	57.1	60.8	64.6
0.34	22.3	28.8	35.2	41.9	46.6	52.0	55.6	60.2	63.3
0.35	21.3	28.0	34.2	41.0	45.8	50.7	55.4	58.5	62.8
0.36	20.7	27.1	33.7	40.1	45.4	49.8	54.2	58.3	62.2
0.37	19.7	26.8	32.7	39.3	44.5	48.8	53.9	57.0	61.4
0.38	19.3	25.8	32.4	38.0	44.0	48.5	52.8	57.3	60.4
0.39	18.7	25.1	31.6	37.6	42.8	47.5	52.7	56.8	59.7
0.4	18.3	24.3	30.0	36.9	42.0	47.4	52.1	55.8	59.4

Table 14. Lower 90% confidence limit of percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 2-year rotation fishery on *T. nuttallii*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	93.7	94.3	94.9	95.6	95.9	96.3	96.8	97.1	97.3
0.02	87.9	89.0	90.2	91.2	92.1	93.0	93.4	94.3	94.9
0.03	82.2	84.0	85.7	87.3	89.0	89.5	90.8	91.6	92.0
0.04	77.1	79.8	81.4	83.6	85.2	86.1	87.7	89.1	90.2
0.05	72.4	75.0	77.7	79.8	81.7	83.3	85.3	86.9	88.0
0.06	67.9	71.4	73.6	76.6	79.0	80.9	82.5	84.0	85.4
0.07	64.0	66.9	70.3	73.4	75.6	77.7	79.8	81.8	83.7
0.08	60.2	63.3	67.0	70.1	73.0	75.5	77.9	79.1	81.1
0.09	56.4	60.3	63.3	66.9	70.3	72.8	75.4	77.1	78.7
0.1	53.5	57.5	61.0	64.7	67.8	70.7	72.5	74.9	76.9
0.11	49.8	54.2	57.9	61.7	65.2	68.2	71.0	74.1	75.6
0.12	47.3	51.0	55.7	59.9	63.1	66.2	69.4	71.5	73.9
0.13	44.9	48.7	53.9	57.0	61.4	63.1	66.9	69.3	71.9
0.14	42.3	46.5	50.5	54.6	59.1	61.7	64.8	67.4	69.9
0.15	40.1	44.0	48.0	52.9	56.4	60.0	63.4	65.0	68.8
0.16	37.6	40.9	46.0	51.3	54.8	58.0	61.4	64.7	67.8
0.17	35.5	39.4	43.8	48.0	52.7	57.1	60.5	63.9	65.9
0.18	33.8	38.0	42.4	46.1	51.4	55.2	59.3	62.5	64.0
0.19	32.2	36.2	40.0	45.2	49.3	53.8	57.2	60.3	63.0
0.2	30.6	34.8	39.1	43.3	47.3	52.0	55.7	58.5	61.6
0.21	29.0	32.6	37.3	41.7	46.0	50.1	54.3	56.1	60.0
0.22	27.3	31.4	36.2	40.0	44.9	48.7	52.8	54.7	58.2
0.23	26.1	30.4	34.0	39.4	43.6	46.6	50.7	53.0	57.3
0.24	24.7	29.5	34.0	36.9	41.7	45.8	49.7	52.6	55.6
0.25	23.3	27.4	31.3	35.8	40.7	43.4	47.8	52.1	55.4
0.26	22.2	25.5	31.2	34.7	39.1	44.2	47.6	51.5	53.7
0.27	21.7	25.3	29.8	33.2	37.0	42.3	46.8	49.1	52.4
0.28	20.1	23.5	28.1	32.4	36.9	40.8	44.5	47.3	50.9
0.29	19.5	23.0	27.4	31.2	34.6	40.5	44.1	48.3	49.7
0.3	18.4	22.1	26.3	30.7	34.2	38.1	42.3	46.6	49.5
0.31	17.9	21.2	25.1	29.2	33.8	37.3	41.5	45.8	47.7
0.32	16.6	20.9	24.7	28.4	32.5	35.8	41.2	45.5	48.5
0.33	16.0	19.9	23.5	27.7	31.5	35.9	39.6	43.2	48.0
0.34	15.6	19.2	22.1	28.1	30.1	34.9	37.5	42.3	44.5
0.35	14.8	18.2	21.4	26.2	28.8	33.5	37.4	40.8	45.2
0.36	14.3	17.4	21.6	25.3	29.4	31.7	36.5	40.6	44.2
0.37	13.5	17.1	20.0	24.8	27.3	31.0	35.8	38.8	43.4
0.38	13.2	16.4	20.0	23.7	28.2	31.2	35.8	39.8	42.7
0.39	12.7	15.7	19.2	23.1	26.9	30.2	35.4	39.0	40.5
0.4	12.4	15.0	18.0	22.5	25.5	30.5	34.4	38.1	41.3

Table 15. Average percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 3-year rotation fishery on *T. nuttallii*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	96.4	97.1	97.5	97.9	98.3	98.5	98.7	98.8	99.0
0.02	93.0	94.1	95.2	96.0	96.5	97.0	97.4	97.8	98.0
0.03	89.6	91.4	92.9	93.9	94.9	95.6	96.1	96.6	97.0
0.04	86.4	88.7	90.5	92.0	93.2	94.2	94.8	95.5	96.0
0.05	83.4	86.0	88.4	90.2	91.6	92.8	93.7	94.5	95.1
0.06	80.5	83.7	86.3	88.3	90.0	91.3	92.4	93.4	94.1
0.07	77.8	81.2	83.9	86.4	88.7	90.0	91.3	92.4	93.2
0.08	75.1	79.0	82.3	85.1	86.8	89.0	90.1	91.5	92.2
0.09	72.4	76.7	80.5	83.2	85.6	87.6	89.0	90.4	91.4
0.1	70.0	74.3	78.6	81.7	84.0	86.2	87.8	89.2	90.2
0.11	67.5	72.4	76.4	79.8	82.8	84.8	86.9	88.1	89.4
0.12	65.3	70.7	75.0	78.4	81.5	83.7	85.9	87.3	88.6
0.13	63.1	68.3	73.4	76.9	80.0	82.4	84.7	86.4	88.0
0.14	60.9	66.5	71.4	74.9	78.5	81.1	83.4	85.3	86.7
0.15	58.7	64.5	69.8	74.1	77.1	80.0	82.5	84.5	86.0
0.16	57.0	62.7	68.1	72.6	76.2	78.9	81.5	83.7	85.4
0.17	55.0	61.4	66.9	71.2	75.1	78.4	80.6	82.9	84.5
0.18	53.4	59.5	65.0	69.9	73.6	76.9	79.8	81.8	83.3
0.19	51.4	58.1	63.8	68.3	72.2	75.3	78.3	81.1	82.9
0.2	49.8	56.6	62.6	67.4	70.8	75.0	77.5	80.3	82.3
0.21	48.4	54.8	60.7	66.5	69.9	73.8	76.5	79.2	81.5
0.22	46.6	53.6	59.6	64.8	69.1	73.1	75.9	78.3	80.6
0.23	45.3	52.1	58.1	63.5	68.1	72.1	75.5	77.9	79.6
0.24	43.9	51.0	57.3	62.6	66.5	70.5	73.9	76.8	79.1
0.25	42.2	49.1	56.3	61.4	65.7	69.7	72.5	76.0	78.3
0.26	41.1	48.4	54.3	60.4	65.2	69.2	71.8	74.8	77.7
0.27	39.9	47.0	53.1	59.1	64.7	67.6	71.5	74.2	76.5
0.28	38.7	45.5	52.3	57.9	62.7	66.6	70.8	73.3	76.4
0.29	37.0	44.7	51.3	57.1	62.0	66.3	70.1	72.3	75.7
0.3	36.5	43.4	50.3	55.8	61.0	65.5	68.9	72.0	74.5
0.31	35.1	42.5	49.1	54.6	59.3	64.2	68.0	70.9	74.0
0.32	34.3	41.6	48.0	54.3	58.9	63.6	67.2	71.4	73.6
0.33	33.0	40.5	47.1	53.6	58.0	62.6	66.7	69.6	72.8
0.34	31.9	39.5	46.2	52.2	57.5	62.0	65.5	68.6	71.8
0.35	31.1	38.8	45.4	51.0	56.5	61.3	64.8	68.5	71.2
0.36	30.0	37.4	44.4	50.7	55.3	60.5	64.4	67.6	70.2
0.37	29.4	36.8	43.4	49.2	55.0	59.9	63.2	67.4	70.4
0.38	28.4	36.0	42.4	48.7	54.3	58.8	62.4	66.4	69.6
0.39	27.9	35.0	41.7	47.9	53.7	57.8	61.9	66.1	68.5
0.4	26.8	34.2	40.7	46.8	52.6	56.5	61.3	64.8	67.6

Table 16. Lower 90% confidence limit of percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 3-year rotation fishery on *T. nuttallii*.

Exploitation Rate	Instantaneous Natural Mortality Rate								
	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	95.7	96.2	96.6	96.9	97.3	97.6	97.8	97.9	98.2
0.02	91.6	92.4	93.4	94.1	94.6	95.2	95.8	96.2	96.4
0.03	87.7	89.0	90.3	91.2	92.2	92.9	93.6	94.2	94.8
0.04	83.9	85.5	87.0	88.4	89.5	90.9	91.8	92.3	93.0
0.05	80.4	82.1	84.2	85.7	87.2	88.8	89.8	90.9	91.6
0.06	77.0	79.3	81.3	83.2	84.8	86.3	87.5	89.1	89.8
0.07	73.9	76.2	78.1	80.4	83.0	84.3	85.8	87.6	88.5
0.08	70.8	73.5	76.1	78.7	80.1	82.9	84.1	86.0	86.6
0.09	67.9	70.7	73.8	76.2	78.6	80.6	82.7	84.2	85.1
0.1	65.2	67.6	71.5	74.3	76.2	78.5	80.1	81.9	83.4
0.11	62.3	65.5	68.3	71.4	74.5	76.7	78.9	80.4	82.2
0.12	59.6	63.2	66.9	69.6	72.8	74.9	77.7	79.6	80.7
0.13	57.2	60.7	64.8	67.5	71.1	73.4	76.2	78.0	80.1
0.14	55.0	58.1	62.5	64.9	68.6	71.0	73.9	75.9	77.9
0.15	52.5	55.9	60.1	63.5	66.4	69.6	72.6	74.8	76.2
0.16	50.6	54.0	57.9	62.4	65.9	67.9	71.0	73.8	76.0
0.17	48.5	52.8	56.5	60.2	63.9	68.3	69.8	72.7	74.7
0.18	46.6	50.2	54.3	58.9	61.7	65.0	69.0	71.1	72.5
0.19	44.5	48.5	53.1	56.4	60.4	63.5	66.2	69.9	72.8
0.2	42.6	47.1	51.3	55.3	58.4	62.7	65.5	69.5	71.2
0.21	41.6	45.0	48.7	54.4	56.8	61.3	64.1	67.2	70.2
0.22	39.4	43.4	47.7	52.0	56.3	61.1	63.2	66.0	69.0
0.23	37.8	42.2	46.1	50.8	55.1	59.0	62.6	65.4	66.5
0.24	36.5	40.6	45.6	49.3	52.3	57.0	60.5	64.2	66.7
0.25	34.9	38.6	44.3	48.0	52.4	56.0	58.2	62.8	65.6
0.26	33.6	37.7	42.2	47.3	51.1	55.4	57.2	60.9	64.4
0.27	32.5	36.5	40.5	45.8	51.3	52.9	56.9	60.2	62.9
0.28	31.4	35.3	39.4	44.3	48.3	51.3	56.6	58.5	62.7
0.29	29.6	34.1	39.1	42.9	47.7	51.2	55.2	57.7	62.1
0.3	29.1	32.8	37.6	42.3	46.5	50.5	53.6	57.4	60.4
0.31	27.9	32.0	36.4	40.0	44.0	48.8	52.4	55.1	58.9
0.32	26.9	30.7	35.2	40.8	44.2	48.3	51.3	57.2	58.9
0.33	25.6	29.8	33.9	39.3	42.8	47.3	51.2	54.4	57.0
0.34	24.6	29.0	33.2	38.2	42.2	45.4	48.8	52.3	56.6
0.35	23.8	28.6	32.1	36.2	40.6	45.4	48.3	53.2	55.3
0.36	23.0	27.1	31.3	35.7	39.3	44.7	48.1	51.5	54.1
0.37	22.0	26.3	30.0	34.4	39.3	44.4	46.4	52.0	54.9
0.38	21.3	25.1	28.8	33.7	38.6	42.3	44.9	50.2	53.5
0.39	20.7	24.5	28.9	32.9	38.4	40.9	44.6	49.5	51.8
0.4	19.8	23.6	27.8	32.0	36.7	38.6	44.2	47.5	50.5

Table 17. Average percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 1-year rotation fishery on *T. capax*.

Exploitation Rate	Instantaneous Natural Mortality Rate								
	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	88.3	90.0	91.4	92.6	93.5	94.3	95.0	95.4	95.8
0.02	78.1	81.2	83.7	85.8	87.5	88.8	90.0	91.1	91.9
0.03	69.2	73.3	77.2	79.9	82.3	84.1	85.5	87.2	88.2
0.04	61.9	66.6	70.7	74.4	77.1	79.3	81.8	83.1	84.8
0.05	55.3	60.5	65.3	69.3	72.4	75.7	77.4	79.8	81.6
0.06	49.5	55.0	60.2	64.8	68.2	71.8	73.9	75.9	78.4
0.07	44.4	50.5	56.1	60.4	64.6	67.7	70.5	73.3	75.2
0.08	40.2	46.4	51.7	56.7	60.7	64.7	67.4	70.5	72.7
0.09	36.2	42.4	48.1	52.9	57.5	61.4	64.4	67.8	69.7
0.1	33.0	39.0	44.8	50.4	54.3	58.6	61.6	65.0	67.6
0.11	30.0	36.3	41.8	46.6	51.6	55.8	59.4	62.1	64.6
0.12	27.1	33.4	39.1	44.6	48.7	52.8	56.4	59.5	62.8
0.13	25.0	30.9	36.8	42.2	46.7	50.1	54.7	57.9	60.8
0.14	22.8	28.7	34.4	39.9	44.3	48.2	52.0	55.4	58.6
0.15	20.9	26.6	32.1	37.4	42.1	46.1	50.7	53.3	56.5
0.16	19.2	24.6	30.3	35.7	40.6	44.4	48.4	51.3	54.4
0.17	17.8	23.2	28.9	33.3	38.0	42.9	46.5	49.6	52.9
0.18	16.6	21.7	26.7	31.6	36.4	41.0	44.7	48.3	51.0
0.19	15.2	20.3	25.1	30.4	34.7	39.0	43.0	46.5	49.4
0.2	14.1	18.9	23.9	28.7	33.2	37.4	41.2	44.5	48.4
0.21	13.2	17.9	22.8	27.2	31.4	35.9	39.9	43.1	46.1
0.22	12.2	16.6	21.2	26.0	30.6	34.5	38.1	41.8	44.7
0.23	11.2	15.8	20.3	24.7	29.1	32.9	36.5	40.6	43.3
0.24	10.6	14.6	19.3	23.6	27.9	32.0	35.5	39.2	41.7
0.25	10.0	14.0	17.8	22.3	26.9	30.2	34.4	37.9	41.1
0.26	9.4	13.0	17.3	21.4	25.6	29.4	33.5	36.5	39.9
0.27	8.7	12.3	16.3	20.8	24.5	28.3	32.5	36.0	39.1
0.28	8.2	11.9	15.5	19.7	23.1	27.7	31.2	34.2	37.7
0.29	7.7	11.2	14.9	18.8	22.7	26.4	30.0	33.9	36.7
0.3	7.2	10.7	14.2	17.9	21.8	25.5	28.7	32.3	35.7
0.31	6.9	10.1	13.4	17.2	20.8	24.4	28.1	31.5	33.9
0.32	6.4	9.4	13.0	16.7	20.0	23.8	27.0	30.4	34.1
0.33	6.1	8.9	12.5	15.7	19.5	22.2	25.9	29.5	32.5
0.34	5.7	8.6	12.0	15.5	18.8	22.1	25.5	28.8	31.7
0.35	5.5	8.4	11.2	14.5	17.9	21.4	24.9	28.0	30.8
0.36	5.2	7.7	10.9	13.9	17.5	20.7	23.9	27.1	29.9
0.37	4.9	7.5	10.4	13.5	16.8	19.5	23.4	26.0	29.6
0.38	4.7	7.2	10.1	13.1	16.2	19.5	22.0	25.7	28.1
0.39	4.5	6.8	9.8	12.5	15.7	19.0	22.1	24.6	27.5
0.4	4.2	6.6	8.8	12.1	14.7	18.1	21.0	23.9	26.9

Table 18. Lower 90% confidence limit of percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 1-year rotation fishery on *T. capax*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	86.4	87.6	88.7	89.7	90.8	91.6	92.5	92.9	93.5
0.02	74.8	76.8	78.9	80.7	82.7	83.7	85.1	86.3	87.3
0.03	64.8	67.6	70.4	73.1	75.1	77.0	78.5	80.8	81.8
0.04	56.9	59.7	62.9	65.7	68.2	70.1	73.2	74.6	77.2
0.05	49.7	53.0	56.2	59.7	62.6	65.9	67.6	70.3	72.4
0.06	43.9	46.6	50.6	54.3	57.1	60.2	63.3	64.5	68.0
0.07	38.2	41.6	45.6	49.0	53.3	55.7	58.2	61.9	63.5
0.08	33.8	37.2	40.6	45.1	48.5	52.1	54.3	58.4	60.4
0.09	29.8	33.2	37.0	40.4	44.7	48.6	50.1	54.8	56.0
0.1	26.5	29.6	33.7	37.9	41.0	45.1	47.2	51.1	54.3
0.11	23.8	27.3	30.3	33.2	37.8	42.0	44.4	47.1	50.1
0.12	20.7	24.3	28.3	32.2	35.3	38.1	41.1	44.2	47.9
0.13	19.0	22.2	25.4	29.8	32.4	35.4	39.8	42.6	45.7
0.14	17.1	19.7	23.5	26.9	30.1	34.0	36.5	39.6	42.7
0.15	15.3	18.1	21.3	24.9	28.4	31.5	35.5	37.1	40.4
0.16	14.0	16.3	19.4	23.5	26.9	29.2	32.9	35.1	37.5
0.17	12.5	15.2	18.4	21.5	23.8	28.2	30.9	33.0	36.0
0.18	11.7	13.6	16.5	19.4	22.8	26.8	29.3	32.5	34.5
0.19	10.4	12.8	15.0	18.4	21.3	24.7	27.3	30.7	32.6
0.2	9.6	11.4	14.2	16.8	19.6	22.4	25.8	28.6	31.6
0.21	8.9	10.8	13.5	15.8	18.3	21.4	24.8	26.5	29.4
0.22	7.9	9.8	11.8	14.3	17.5	20.2	22.2	26.2	27.6
0.23	7.1	9.1	11.1	13.9	16.4	19.0	20.9	24.3	26.6
0.24	6.8	8.2	10.7	12.6	15.1	18.4	19.9	23.6	24.8
0.25	6.2	7.8	9.2	11.8	14.1	16.6	19.3	22.2	24.5
0.26	5.9	6.8	9.3	11.1	13.4	15.7	18.4	20.5	23.0
0.27	5.3	6.7	8.2	10.7	12.3	15.5	18.0	20.6	23.2
0.28	4.9	6.3	7.8	9.8	11.2	14.4	16.5	18.7	21.3
0.29	4.6	5.6	7.0	9.3	11.2	13.1	16.2	19.2	21.0
0.3	4.1	5.6	6.8	8.7	11.1	12.7	14.5	17.3	19.8
0.31	4.0	5.1	6.4	8.1	9.8	11.7	13.9	16.3	17.9
0.32	3.7	4.6	5.8	7.7	9.1	11.7	13.9	15.4	18.5
0.33	3.4	4.4	5.8	7.1	8.8	10.1	12.4	15.0	16.8
0.34	3.2	4.2	5.6	6.8	8.5	10.1	12.4	14.3	16.5
0.35	3.1	3.9	5.0	6.1	7.7	9.6	12.3	13.8	15.2
0.36	2.7	3.4	4.7	6.2	7.4	9.1	11.2	13.3	15.4
0.37	2.6	3.4	4.6	5.6	6.9	8.0	10.4	12.3	14.7
0.38	2.5	3.2	4.3	5.4	6.7	8.1	9.4	11.9	14.1
0.39	2.4	3.0	4.3	5.0	6.4	8.3	10.2	11.5	13.1
0.4	2.2	3.0	3.3	4.9	6.0	7.5	8.9	10.6	12.2

Table 19. Average percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 2-year rotation fishery on *T. capax*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	*0.1*	*0.15*	*0.2*	*0.25*	0.3	0.35	0.4	0.45	0.5
0.01	93.8	94.8	95.6	96.2	96.7	97.1	97.3	97.7	97.8
0.02	88.1	89.9	91.3	92.6	93.4	94.3	94.8	95.4	95.9
0.03	82.8	85.3	87.3	88.9	90.3	91.5	92.5	93.3	93.9
0.04	77.7	80.9	83.4	85.7	87.6	88.8	90.1	91.0	91.7
0.05	73.1	76.8	79.9	82.5	84.6	86.4	87.8	88.8	90.2
0.06	68.8	72.8	76.6	79.4	81.6	84.0	85.3	86.8	88.2
0.07	64.7	69.5	73.3	76.5	79.1	81.6	83.3	84.5	86.3
0.08	60.9	66.2	69.9	74.0	76.8	78.9	81.2	83.1	84.4
0.09	57.7	62.8	67.6	71.4	74.4	76.8	79.0	81.1	82.7
0.1	54.2	59.9	64.6	68.3	72.1	75.1	77.3	79.3	81.1
0.11	51.1	57.0	61.6	66.1	69.7	72.8	75.2	77.7	79.5
0.12	48.3	54.3	59.6	64.0	67.5	70.7	73.2	75.7	78.0
0.13	45.6	51.8	57.1	61.7	65.5	68.7	71.5	73.9	76.0
0.14	43.2	49.4	54.6	59.6	63.3	67.1	70.3	72.8	74.7
0.15	40.8	47.1	52.5	57.2	61.6	65.3	68.7	70.7	73.5
0.16	38.7	44.8	50.7	56.0	59.6	63.4	66.9	69.8	71.8
0.17	36.4	42.7	48.7	53.4	57.8	62.1	64.9	67.7	70.2
0.18	34.6	40.8	46.8	51.9	56.3	60.0	64.2	66.6	69.0
0.19	32.7	39.1	45.0	50.2	55.0	58.6	62.3	65.0	67.8
0.2	31.1	37.2	43.4	48.5	52.6	57.5	60.9	63.8	66.2
0.21	29.4	35.8	41.4	46.8	51.7	55.5	58.7	61.9	65.0
0.22	27.8	33.9	40.1	45.3	49.4	54.0	58.1	60.9	63.8
0.23	26.6	32.9	38.7	43.8	48.1	53.0	56.6	59.4	62.5
0.24	25.2	31.1	37.2	42.7	47.2	51.3	55.3	58.3	61.4
0.25	24.1	30.3	35.7	40.6	45.4	49.7	53.6	57.7	60.1
0.26	22.7	28.8	34.1	40.1	44.8	49.0	52.2	56.0	59.0
0.27	21.8	27.5	32.8	38.8	43.5	47.5	51.3	54.7	57.9
0.28	20.7	26.2	32.2	37.3	42.0	46.2	50.0	53.4	56.6
0.29	19.9	25.5	30.5	36.5	41.1	44.9	49.2	52.3	55.7
0.3	18.7	24.4	29.9	34.7	39.5	43.9	47.2	52.0	54.3
0.31	17.8	23.5	29.1	34.0	38.8	43.1	46.7	51.0	53.7
0.32	17.0	22.6	27.7	32.7	37.6	41.0	45.6	49.6	52.3
0.33	16.3	21.5	26.9	31.8	35.9	40.3	44.9	48.7	51.5
0.34	15.6	20.7	25.6	30.6	35.8	39.5	43.8	47.0	50.4
0.35	14.8	19.9	25.3	29.7	34.5	38.9	42.2	46.1	50.1
0.36	14.2	19.3	24.0	29.0	33.6	37.7	41.5	45.0	49.0
0.37	13.7	18.5	23.4	28.6	33.0	37.1	40.9	44.6	47.5
0.38	13.0	17.6	22.6	27.6	31.7	36.2	39.8	43.1	47.1
0.39	12.4	17.0	21.8	26.5	30.8	34.9	39.1	42.2	45.6
0.4	12.0	16.5	21.0	25.9	30.2	34.8	38.1	42.0	45.3

Table 20. Lower 90% confidence limit of percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 2-year rotation fishery on *T. capax*.

Exploitation Rate	Instantaneous Natural Mortality Rate								
	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	92.82	93.43	94.11	94.72	95.19	95.59	95.90	96.33	96.54
0.02	86.22	87.34	88.48	89.76	90.51	91.46	91.99	92.79	93.41
0.03	80.16	81.83	83.34	84.65	86.14	87.42	88.53	89.66	90.26
0.04	74.23	76.58	78.39	80.48	82.66	83.53	85.19	86.26	87.04
0.05	69.01	71.77	73.66	76.20	78.47	80.29	81.59	82.91	84.77
0.06	64.31	66.95	69.78	72.01	74.08	77.13	78.20	80.15	82.04
0.07	59.76	62.79	65.94	68.35	70.80	73.50	75.34	76.67	78.77
0.08	55.50	59.07	62.00	65.53	68.19	69.85	72.36	74.64	76.09
0.09	52.10	55.42	58.95	62.09	64.68	66.99	69.15	72.06	73.94
0.1	48.68	51.77	55.00	58.35	61.71	65.41	67.21	69.34	71.46
0.11	45.12	48.83	51.80	55.67	59.00	62.09	64.44	67.51	69.53
0.12	42.25	45.28	49.93	52.82	55.80	59.41	61.90	64.66	67.23
0.13	39.35	42.99	46.99	50.23	53.54	56.57	59.65	62.33	64.29
0.14	36.88	40.76	43.98	47.86	50.56	55.03	58.75	60.94	62.32
0.15	34.42	38.13	41.75	45.15	49.49	52.94	56.22	58.05	61.48
0.16	32.20	35.57	40.06	44.18	46.92	50.37	53.77	56.94	59.21
0.17	30.12	33.79	38.00	40.96	45.02	49.09	51.44	53.79	56.72
0.18	28.02	31.76	35.67	39.36	43.11	46.06	50.81	52.72	55.38
0.19	25.99	29.62	33.61	37.45	41.29	45.16	48.49	51.70	53.45
0.2	24.76	27.95	32.23	35.84	39.22	44.21	46.98	49.79	51.55
0.21	23.06	27.01	29.33	33.03	38.42	41.15	43.61	46.68	50.70
0.22	21.66	24.83	28.89	32.63	35.50	39.45	43.39	45.44	48.87
0.23	20.23	23.79	27.41	31.11	33.53	38.53	41.80	44.01	46.71
0.24	19.07	22.01	25.88	29.74	33.44	36.51	40.20	42.58	45.96
0.25	17.86	21.57	24.29	27.32	31.32	33.91	37.99	42.00	44.69
0.26	16.99	20.34	22.60	27.20	31.06	34.17	36.89	40.60	44.04
0.27	16.16	18.55	21.48	26.11	29.06	32.09	35.86	39.44	42.42
0.28	15.16	17.46	21.36	24.38	27.74	31.24	34.50	36.74	40.49
0.29	14.30	17.01	19.31	24.27	27.25	29.96	33.67	35.44	39.23
0.3	13.21	15.83	18.66	22.13	25.40	28.80	31.07	36.48	38.24
0.31	12.67	15.39	18.33	21.77	25.00	28.24	30.87	35.52	37.37
0.32	11.83	14.16	17.34	20.24	23.45	26.46	29.82	33.93	35.90
0.33	11.15	13.81	16.55	19.68	22.51	25.64	29.34	33.16	34.97
0.34	10.57	12.92	15.52	18.32	22.22	24.45	27.66	30.68	33.33
0.35	9.82	12.52	14.93	17.23	20.62	23.81	26.02	30.34	33.28
0.36	9.28	11.68	14.00	16.92	20.31	23.02	25.96	28.86	32.95
0.37	9.11	11.10	13.78	16.72	20.03	22.45	24.53	28.13	30.47
0.38	8.44	10.22	12.73	16.34	18.38	21.39	24.30	26.51	30.20
0.39	7.92	9.98	12.31	14.71	17.03	20.03	23.44	26.03	28.42
0.4	7.70	9.70	11.58	14.44	17.09	20.59	22.95	25.68	28.33

Table 21. Average percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 3-year rotation fishery on *T. capax*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	95.8	96.5	97.0	97.4	97.7	98.0	98.2	98.4	98.6
0.02	91.8	93.1	94.1	94.9	95.6	96.0	96.5	96.9	97.2
0.03	88.0	89.8	91.1	92.4	93.4	94.1	94.8	95.3	95.7
0.04	84.2	86.6	88.6	90.1	91.3	92.3	93.1	93.8	94.5
0.05	80.8	83.5	85.9	87.8	89.3	90.5	91.6	92.4	93.0
0.06	77.4	80.6	83.5	85.5	87.3	88.8	90.0	90.7	91.6
0.07	74.2	77.8	80.9	83.4	85.4	86.9	88.5	89.7	90.5
0.08	71.1	75.2	78.7	81.0	83.4	85.1	86.8	88.0	89.3
0.09	68.1	72.4	76.3	79.3	81.7	83.9	85.3	86.6	88.0
0.1	65.5	70.0	73.8	77.0	79.8	82.1	83.6	85.6	86.7
0.11	62.9	67.9	71.5	74.9	77.5	80.6	82.5	84.1	85.2
0.12	60.2	65.3	69.9	73.2	76.6	78.6	80.9	82.9	84.1
0.13	57.9	63.3	67.6	71.6	74.5	77.2	79.4	81.3	83.0
0.14	55.6	60.8	66.0	69.9	73.1	76.0	78.0	80.1	81.8
0.15	52.9	58.8	63.8	68.1	71.5	74.5	77.0	78.8	80.9
0.16	50.9	56.6	62.2	66.3	70.2	72.7	75.6	77.6	79.5
0.17	49.0	54.9	60.1	64.6	68.4	71.6	74.2	76.7	78.6
0.18	47.2	53.1	58.9	63.3	66.9	69.9	73.0	75.5	77.2
0.19	45.3	51.5	56.8	61.7	65.0	69.6	71.4	74.4	76.0
0.2	43.5	49.7	55.2	59.8	64.1	67.7	70.3	73.0	74.7
0.21	41.9	48.0	53.5	58.3	62.9	66.2	69.2	71.7	74.1
0.22	40.1	46.7	52.1	57.3	61.2	64.8	68.2	70.4	73.0
0.23	38.6	44.7	50.5	55.4	59.9	63.5	66.7	69.4	71.9
0.24	36.9	43.3	49.2	54.3	58.9	62.3	65.5	68.0	71.0
0.25	35.5	42.0	48.1	53.0	56.9	61.2	64.6	67.4	69.8
0.26	34.2	40.7	46.3	51.9	56.0	59.8	62.9	66.0	68.8
0.27	33.0	39.2	45.3	50.4	54.4	59.0	62.7	65.2	67.6
0.28	31.7	38.2	44.0	49.1	53.9	57.8	61.3	64.3	67.1
0.29	30.4	36.4	42.6	47.8	53.0	56.8	60.1	63.6	66.5
0.3	29.2	35.4	41.5	46.9	51.1	56.0	58.6	62.1	65.2
0.31	28.3	34.6	40.3	45.6	50.7	54.7	57.4	61.4	64.3
0.32	27.1	33.3	39.2	44.4	49.2	53.7	57.3	60.3	63.2
0.33	26.1	32.4	38.5	43.5	48.1	52.7	56.2	60.0	62.4
0.34	25.1	31.3	37.2	43.0	46.8	51.4	55.4	58.5	61.7
0.35	23.8	30.3	36.3	41.3	46.3	50.4	54.8	58.0	60.2
0.36	23.2	29.5	35.5	39.9	45.1	49.2	53.7	57.0	59.4
0.37	22.6	28.5	34.2	39.8	44.4	48.8	52.6	55.8	58.8
0.38	21.4	27.4	33.7	38.4	43.7	47.7	51.9	54.7	57.3
0.39	20.7	26.4	32.7	37.4	42.4	46.9	50.9	53.9	56.7
0.4	20.0	25.8	31.6	36.6	41.5	46.3	50.0	53.1	56.6

Table 22. Lower 90% confidence limit of percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 3-year rotation fishery on *T. capax*.

Exploitation	Instantaneous Natural Mortality Rate								
Rate	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.01	95.1	95.5	96.0	96.4	96.7	97.0	97.3	97.4	97.7
0.02	90.4	91.3	92.2	92.8	93.5	94.0	94.6	95.1	95.4
0.03	86.0	87.1	88.2	89.5	90.5	91.3	92.0	92.7	93.2
0.04	81.6	83.4	84.8	86.4	87.4	88.6	89.5	90.4	91.3
0.05	77.7	79.6	81.4	83.1	84.7	86.0	87.3	88.2	88.8
0.06	74.0	76.2	78.5	80.2	81.9	83.6	85.0	85.4	86.9
0.07	70.3	72.6	75.2	77.4	79.2	80.7	83.1	84.2	85.4
0.08	66.8	69.6	72.2	74.1	76.5	78.4	80.5	81.8	83.2
0.09	63.5	66.3	69.3	72.1	74.6	76.6	78.4	79.4	81.5
0.1	60.6	63.4	66.4	69.1	71.7	74.1	75.5	78.6	79.6
0.11	57.7	60.9	63.2	66.0	68.5	72.2	74.4	76.4	77.5
0.12	54.8	58.1	61.4	64.7	67.9	69.4	72.0	74.0	75.4
0.13	52.3	55.7	59.0	62.3	64.9	67.7	70.3	72.3	73.9
0.14	49.9	53.1	57.2	60.2	63.0	66.2	68.1	70.3	72.3
0.15	46.7	50.7	54.2	58.1	60.9	63.9	66.3	68.8	71.1
0.16	44.7	48.5	52.4	56.2	59.1	61.8	64.6	66.9	69.1
0.17	42.5	46.1	49.8	53.8	57.4	60.6	62.9	65.8	67.8
0.18	40.9	44.6	48.9	52.0	55.1	57.7	61.6	64.9	66.5
0.19	39.1	42.8	46.2	50.2	53.1	58.3	59.2	63.0	64.6
0.2	37.0	40.5	44.6	47.8	52.1	55.4	57.9	61.1	62.3
0.21	35.5	38.9	42.5	46.2	50.2	53.8	56.8	59.4	62.0
0.22	33.6	37.5	41.2	45.5	48.3	52.3	55.5	57.2	60.6
0.23	31.9	35.2	39.1	43.3	46.9	50.2	53.7	56.1	59.3
0.24	30.3	33.5	37.9	41.6	45.8	48.9	52.1	54.2	58.3
0.25	28.6	32.6	36.7	40.1	43.1	47.5	51.0	53.6	56.2
0.26	27.7	31.3	34.7	38.9	42.5	45.8	48.4	52.0	54.7
0.27	26.4	29.8	33.8	38.0	40.8	45.2	48.7	50.3	53.1
0.28	24.9	28.5	32.2	36.6	40.3	43.5	47.0	49.5	52.2
0.29	24.0	26.6	31.1	34.7	40.0	42.5	45.8	49.1	51.9
0.3	23.0	26.0	29.7	34.0	36.8	41.7	43.1	47.5	50.6
0.31	21.9	24.9	28.4	32.7	36.8	39.9	42.4	46.1	48.8
0.32	21.0	24.1	27.4	30.7	35.1	39.3	42.5	44.6	48.4
0.33	20.0	23.0	27.4	30.4	33.8	37.7	40.7	45.3	47.6
0.34	18.8	22.1	26.0	30.2	32.6	36.0	39.7	42.8	46.9
0.35	17.9	21.2	25.1	27.9	32.3	35.7	39.8	42.3	43.8
0.36	17.2	20.5	24.1	27.1	31.2	33.7	38.3	41.5	43.2
0.37	16.5	19.5	23.1	26.4	30.1	33.7	37.2	40.2	42.7
0.38	15.5	18.5	22.2	25.5	29.5	32.6	36.8	38.1	41.0
0.39	15.1	17.7	21.7	24.7	28.2	32.2	35.5	37.7	40.1
0.4	14.2	17.2	20.5	23.2	27.5	31.3	33.7	36.6	40.5

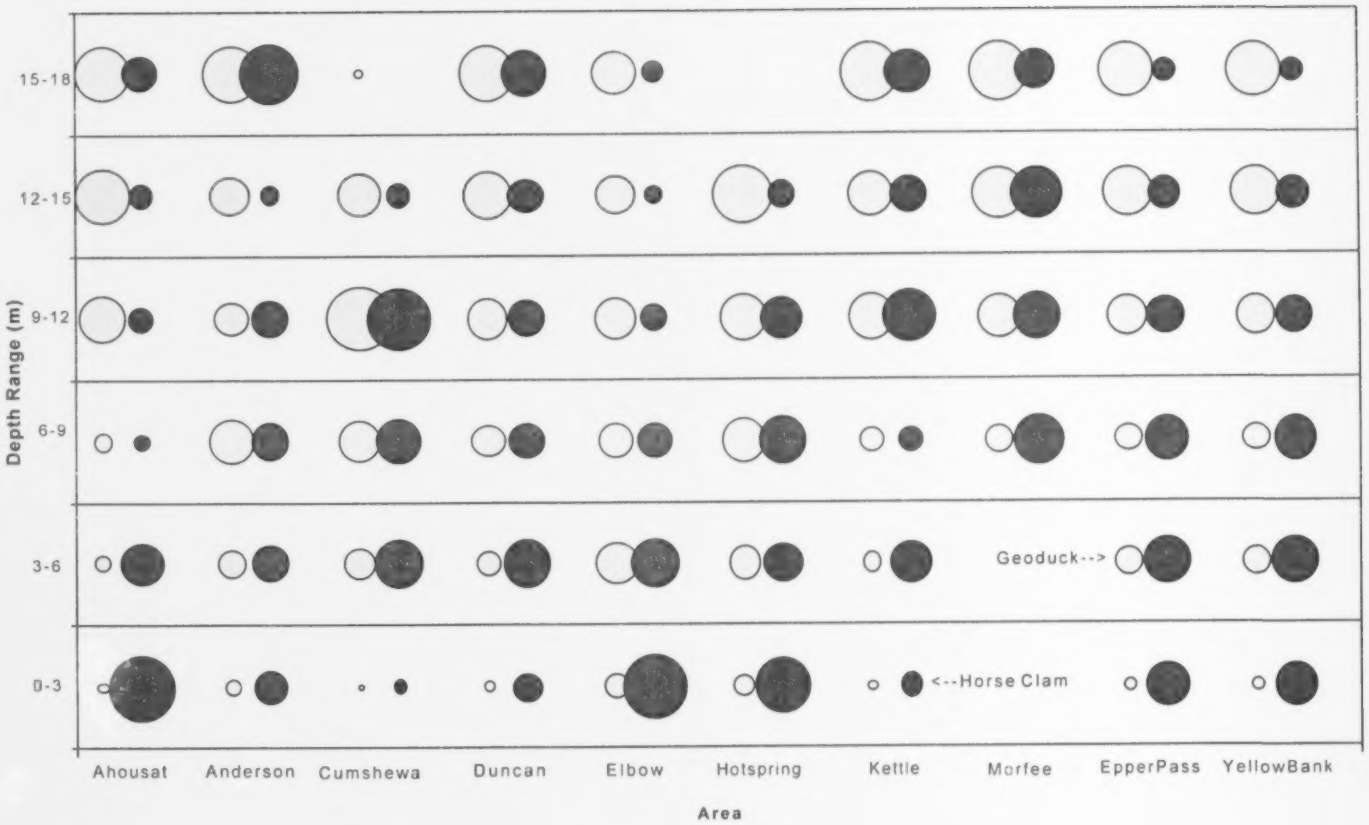

Fig. 1. Relative percentage of geoducks and horse clams in different depth ranges.
(See Table 2 for values)

Fig. 2. Percentage of quadrats with presence of eelgrass in different dpeth ranges.
(See Table 6 for values)

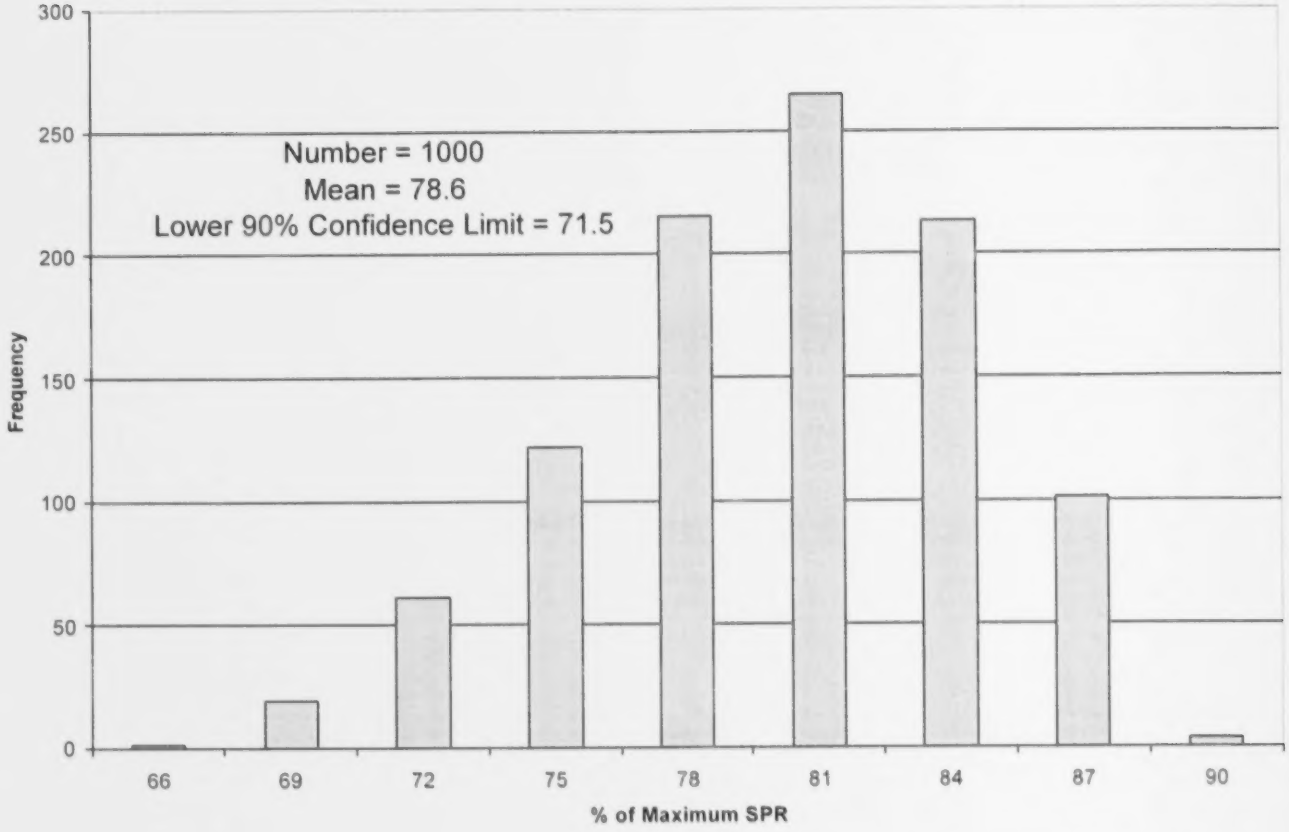

Fig. 3. Frequency distribution of percentage of maximum spawning stock biomass per recruit (SPR) retained in the stock for a 3-year rotation fishery on *T. nuttallii* with natural mortality of 0.2 and exploitation rate of 10%

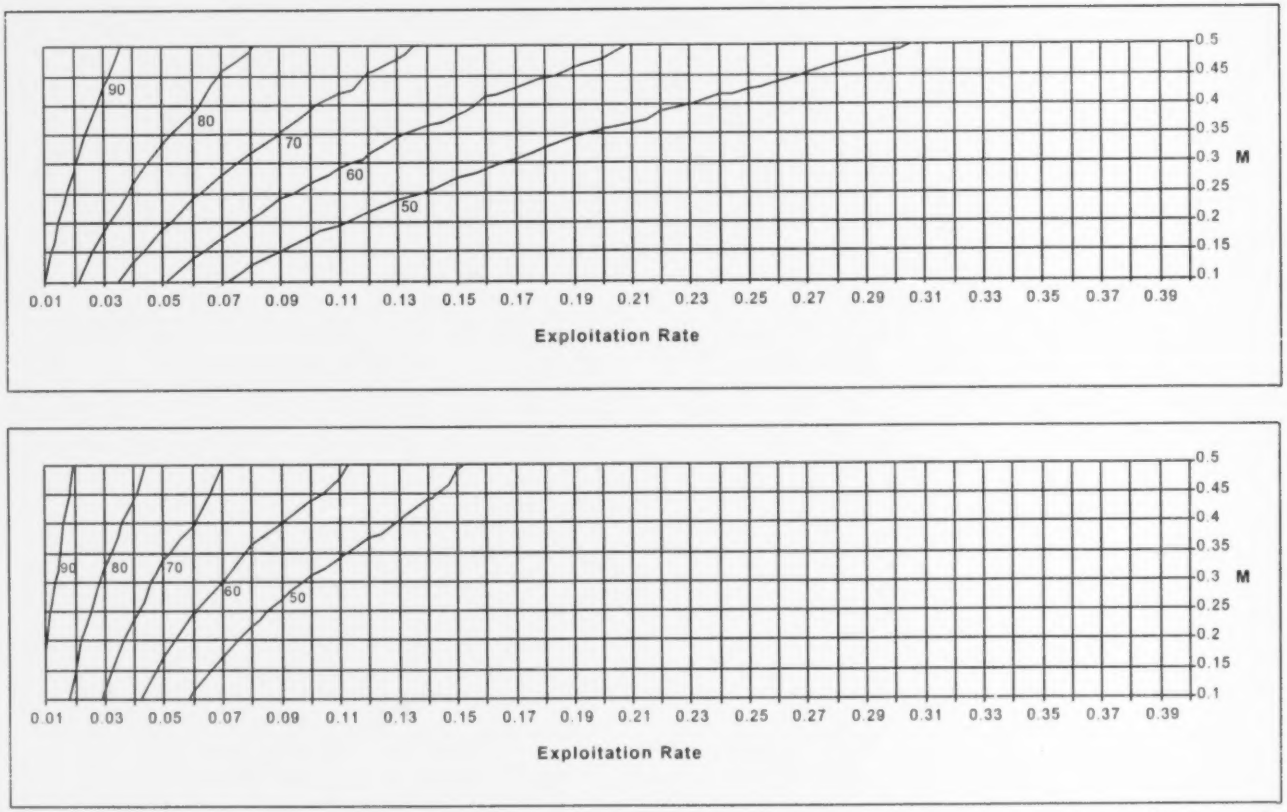

Fig. 4. Percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 1-year rotation fishery on T. nuttallii. (Top: mean; Bottom: Lower bound of 90% confidence interval)

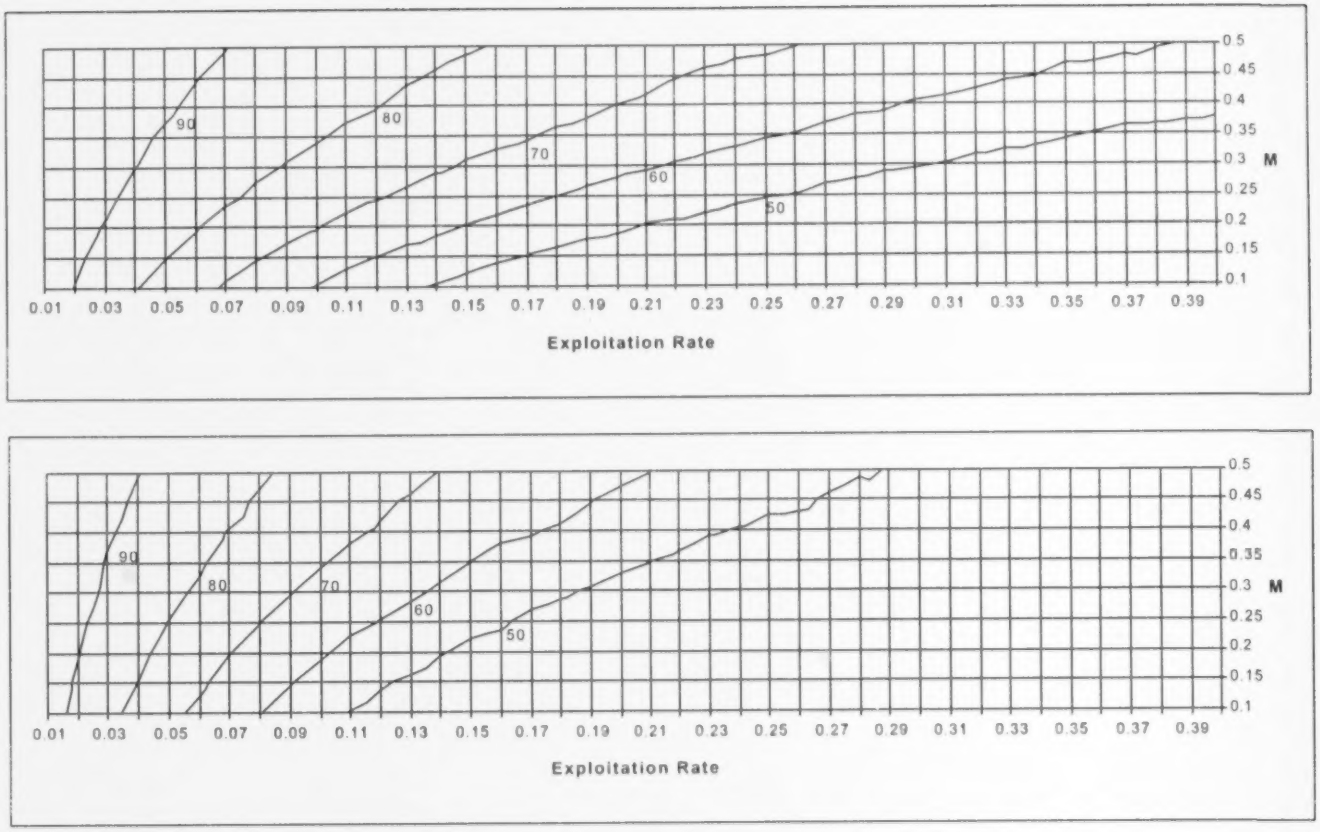

Fig. 5. Percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 2-year rotation fishery on T. nuttallii. (Top: mean; Bottom: Lower bound of 90% confidence interval)

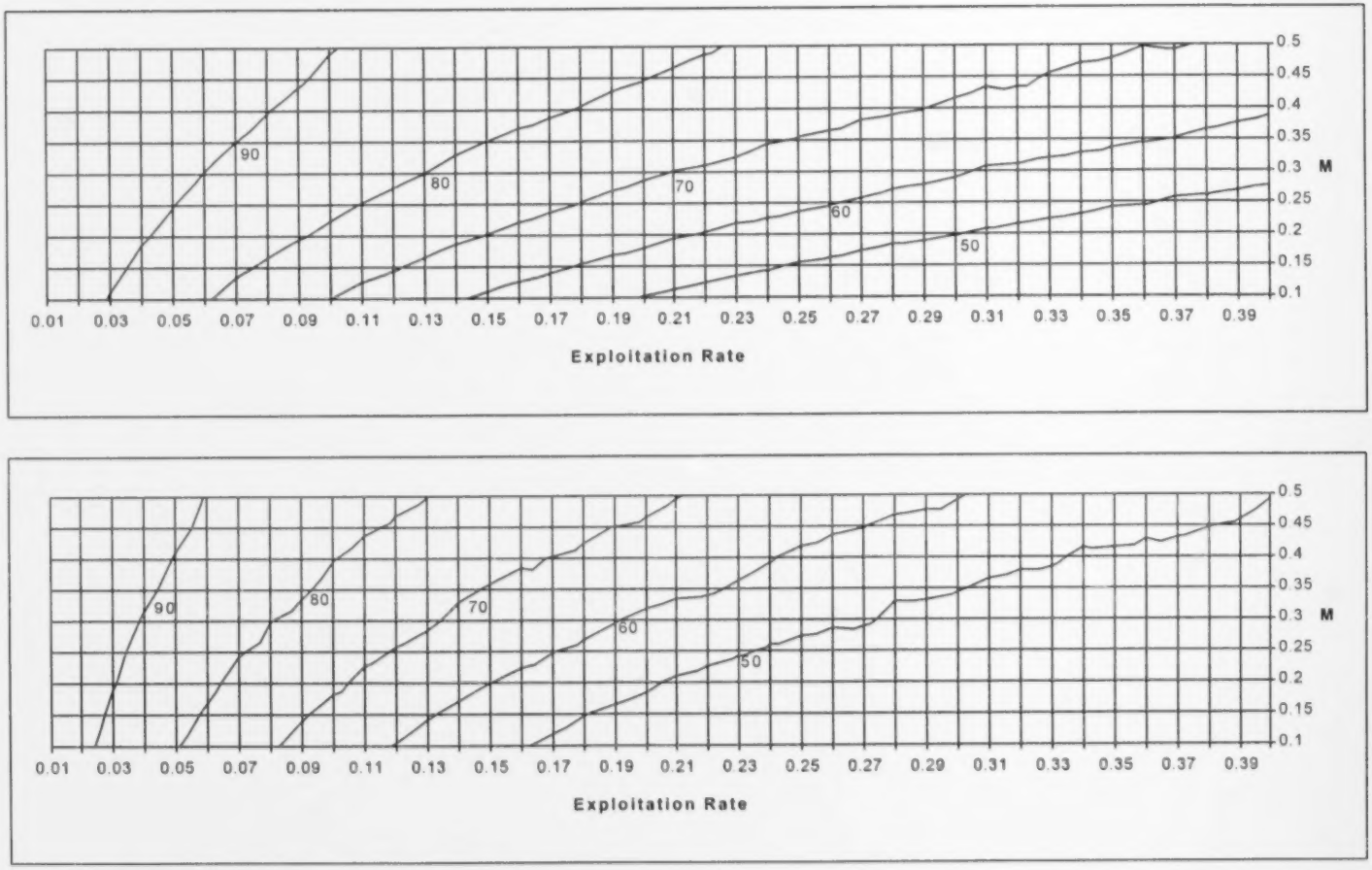

Fig. 6. Percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 3-year rotation fishery on T. nuttallii. (Top: mean; Bottom: Lower bound of 90% confidence interval)

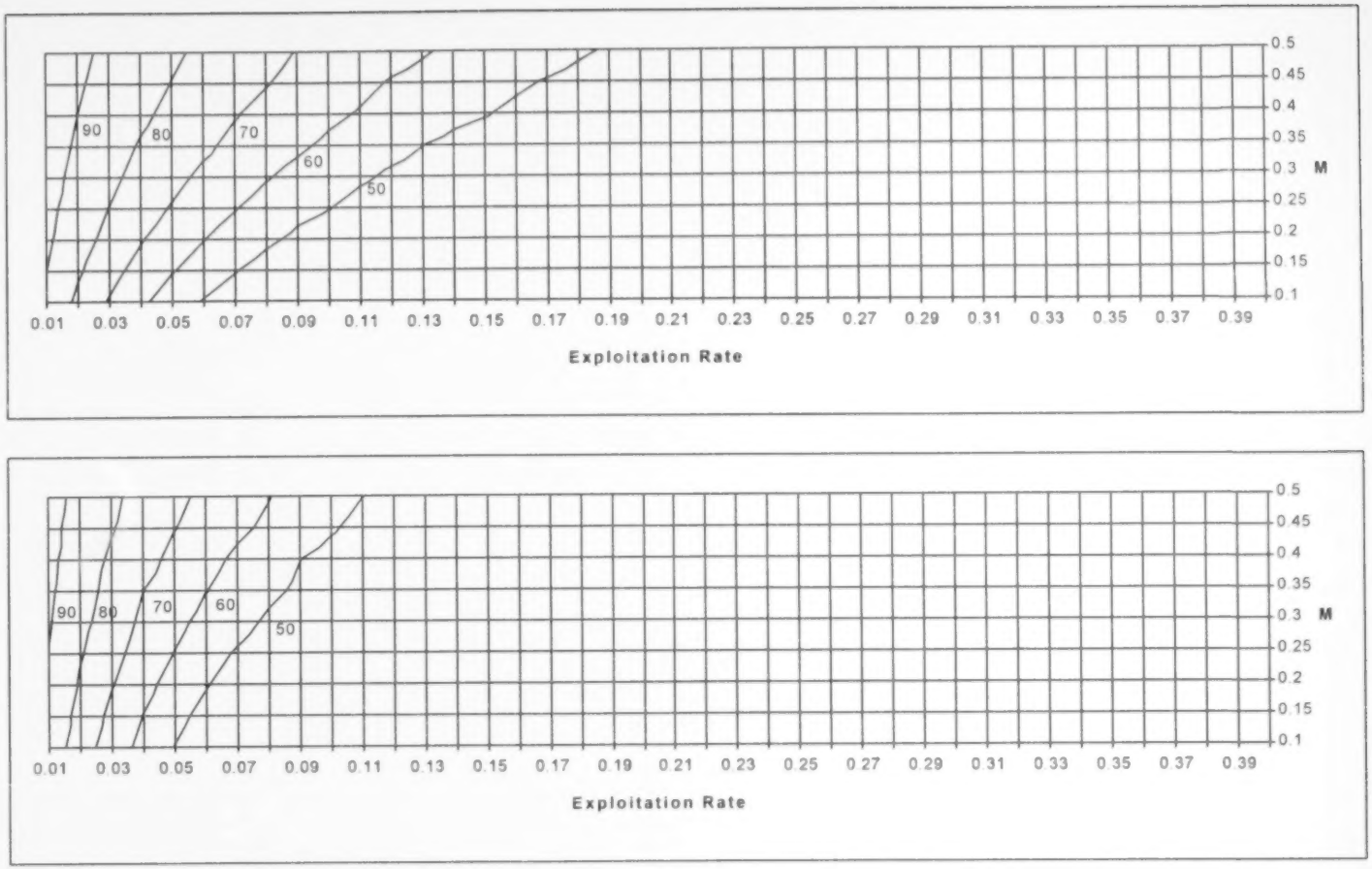

Fig. 7. Percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 1-year rotation fishery on T. capax. (Top: mean; Bottom: Lower bound of 90% confidence interval)

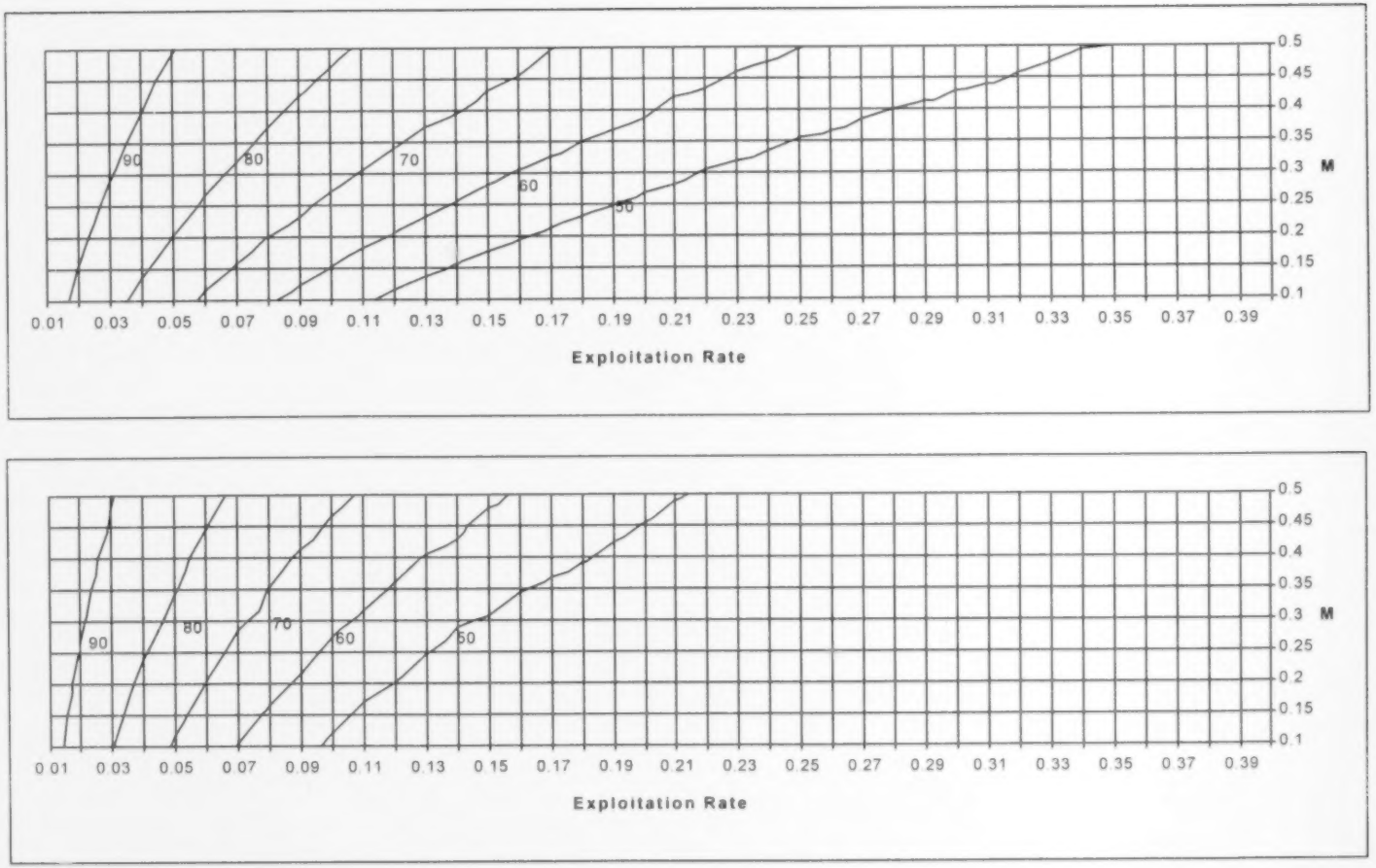

Fig. 8. Percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 2-year rotation fishery on T. capax. (Top: mean; Bottom: Lower bound of 90% confidence interval)

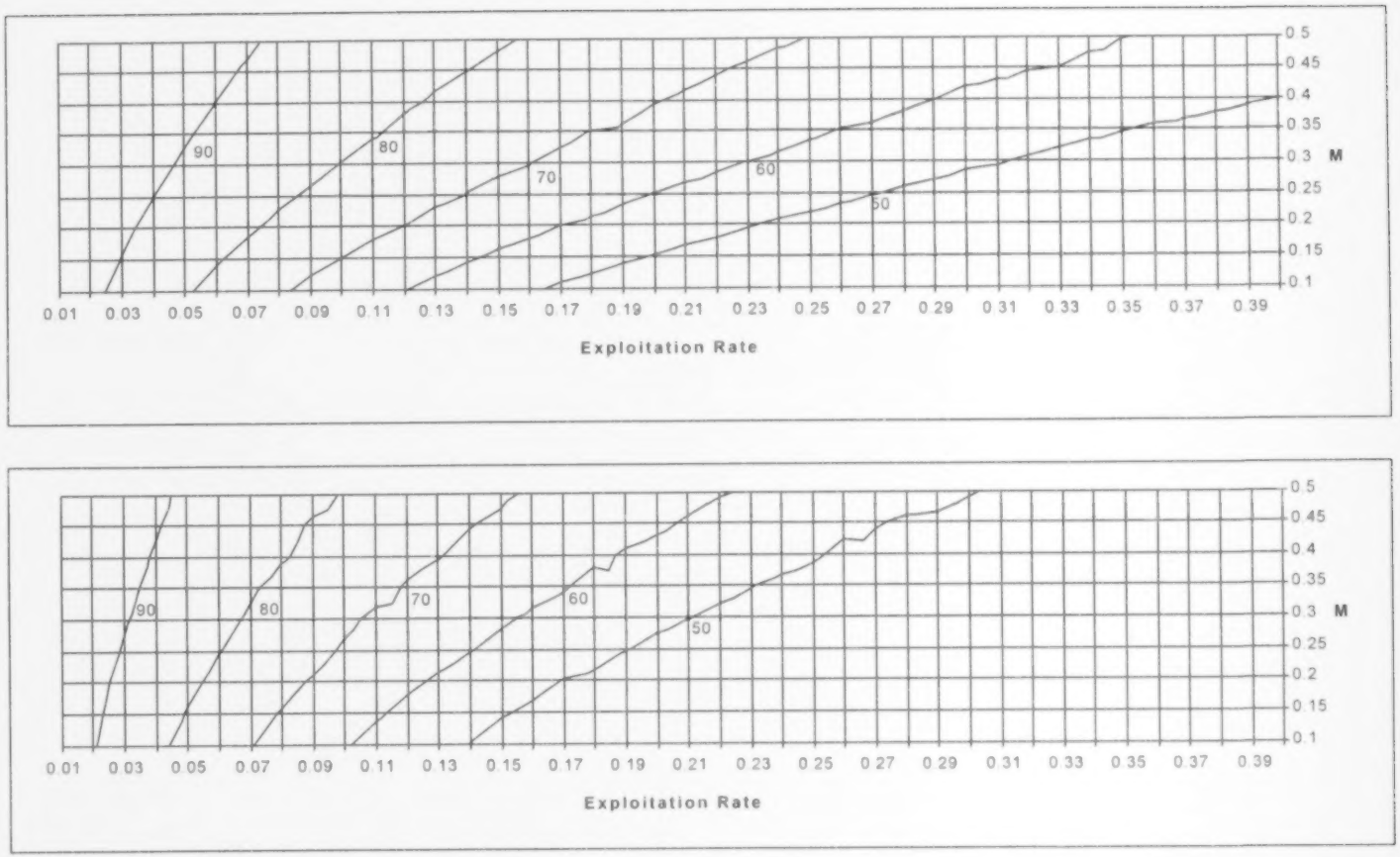

Fig. 9. Percentage of maximum spawning stock biomass per recruit in association with instantaneous natural mortality rate and exploitation rate for 3-year rotation fishery on T. capax. (Top: mean; Bottom: Lower bound of 90% confidence interval)

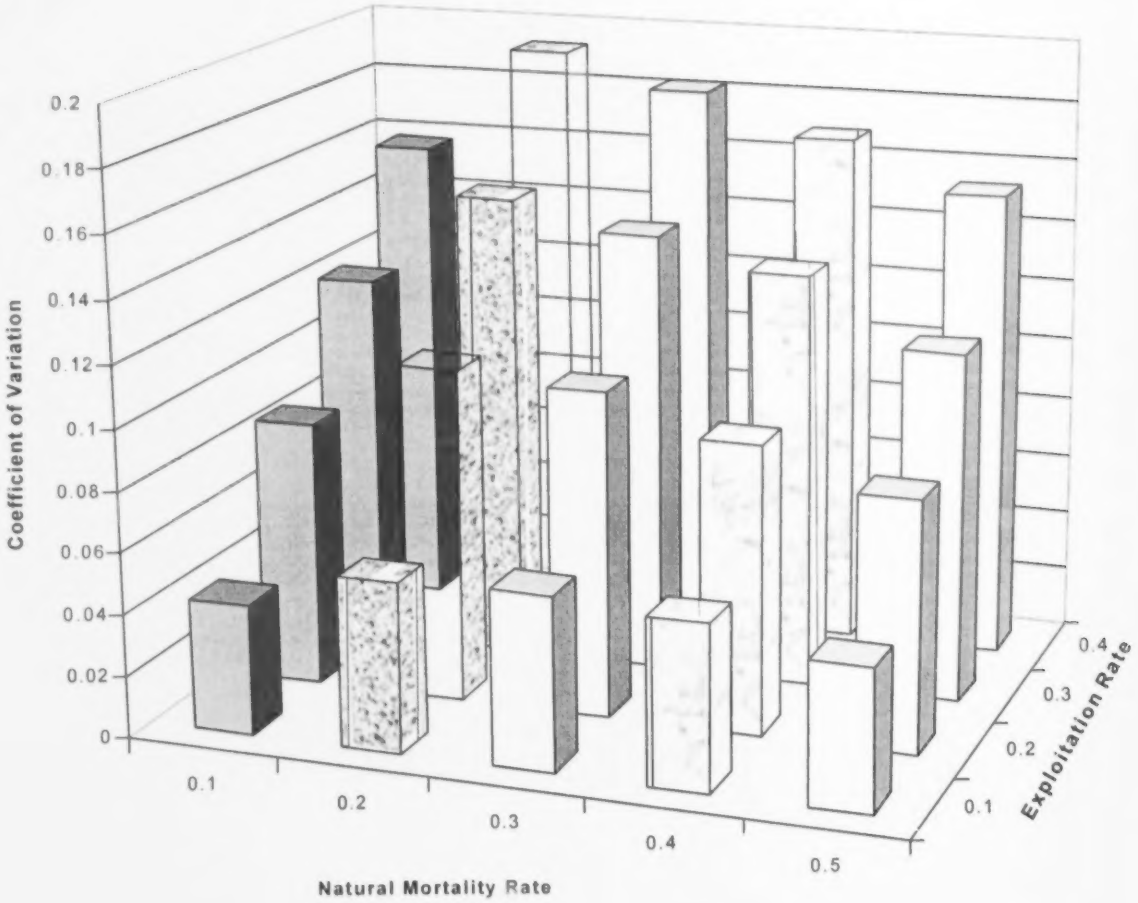

Fig. 10. Relative variation in percentage of maximum spawning stock biomass per recruit for a 3-year rotation fishery on *T. nuttallii*

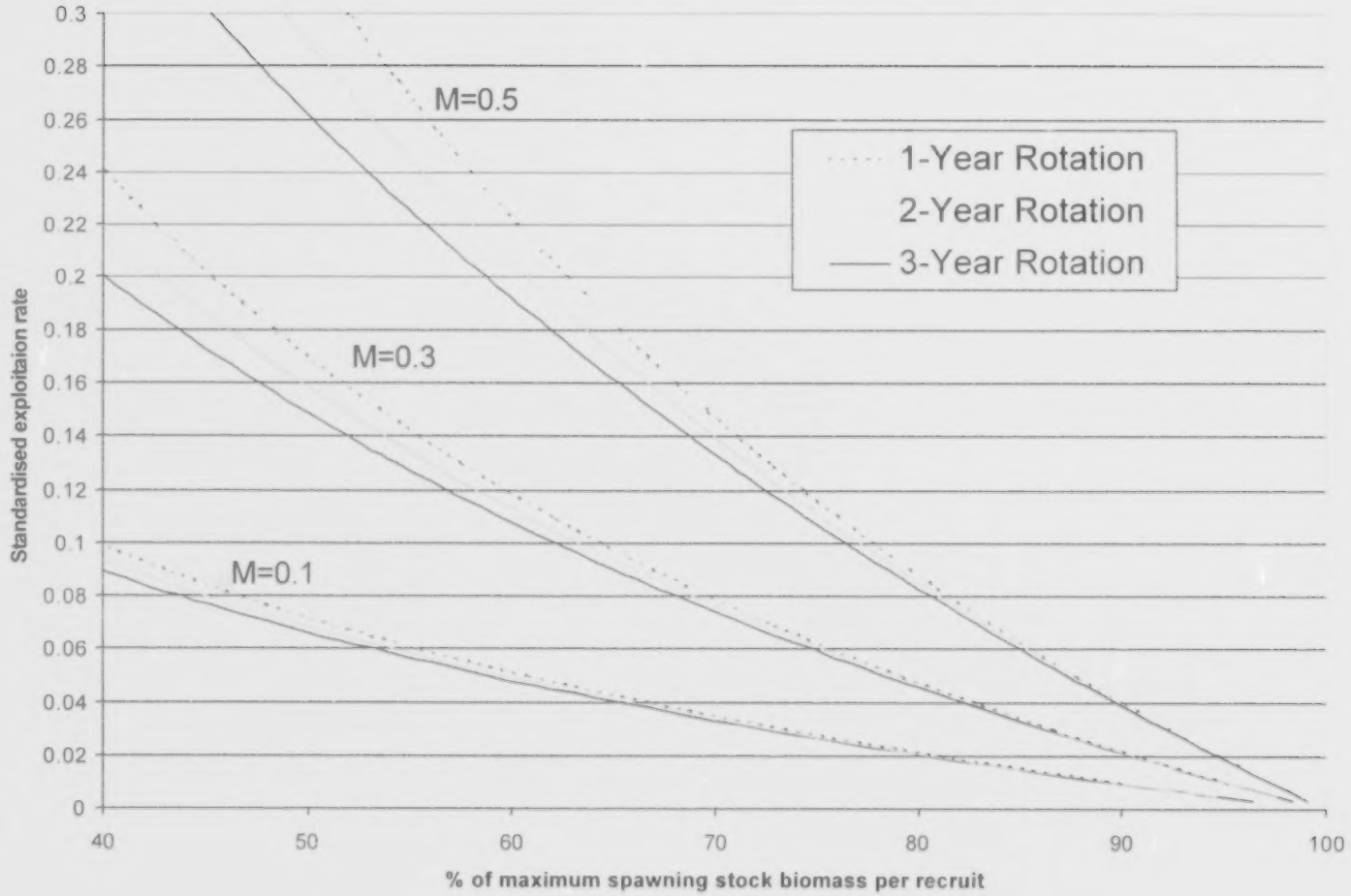

Fig. 11. Effect of rotation years and natural mortality rate on the exploitation rate